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BAKERY
Technology and Engineering

Prepared by a group of specialists and edited by

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Preface

There are a number of good texts on bakery technology which either deal principally with small bake-shop practices or concentrate on fundamental scientific principles to the exclusion of the engineering aspects of the subject. It is not the purpose of the present volume to compete with these works. Instead, we have attempted to provide those interested in bakery science with a discussion of the scientific principles of modern large-scale processing methods and to give them an introduction to the application of automation in the bakery. In order to provide a complete one-volume treatment, rather extensive descriptions of the chemistry and technology of the most important raw materials are included, as well as discussions of the fundamental processing techniques which can be applied to doughs and batters. We believe that our approach is new and that the book fills an important need in the literature of food technology.

This book is a collaborative effort of more than twenty different authors. By using a battery of experts, we hoped to avoid the excessive reliance upon the literature which sometimes results in the perpetuation of errors, and to bring new ideas into print. Authors were selected from among those scientists and engineers who have a close and continuing acquaintance with modern commercial practices in their specialized areas. Attempts were made to obtain authors who had fresh and non-derivative views of their fields.

Bibliographies of considerable length have been appended to most of the chapters. Where the bibliographies are reduced in size, the cause is a dearth of pertinent literature rather than a lack of diligence on the part of the authors.

This book is not directed to cereal chemists and bakery engineers alone, although its most obvious appeal is to these groups. Food technologists connected with industries which supply raw materials for bakery products should find the book helpful in directing new product development and product improvement studies. Marketing and sales personnel should find the material presented to be of value in orienting themselves with respect to factors affecting product quality and the economics of production. Administrators who are not technically trained will find in this one volume a unified treatment of the technology and engineering of their business which can make more meaningful the reports of their research, development, and quality control personnel.

Space limitations preclude the listing of all of the persons who supplied advice, information, reviews, illustrative material, and encouragement during the preparation of the book. Acknowledgements are incomplete for this reason, but the following list includes persons other than authors who reviewed chapters or made other substantial and time-consuming contributions to the book.

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We are not sanguine enough to expect that the book will be without errors. The editor would appreciate having his attention called to any mistakes which the reader may detect. Suggestions for improvement in organization, style, or content will be carefully considered in the preparation of subsequent editions of the volume.

SAMUEL A. MATZ

April 1, 1960

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SECTION I

The Materials of Baking

CHAPTER 1

H. H. Schopmeyer

Flour

WHEAT FLOUR

Wheat flour is unique among the cereal flours in that when mixed with water in correct proportions the protein will form an elastic dough which is capable of holding gas and which will set to a spongy structure when heated in the oven. It is this phenomenon which makes possible the production of wheat bread as we know it.

The peculiar properties of doughs made from wheat flour were explained by Halton and Scott-Blair (1937). They described flour dough as containing protein chains which behave like "coiled springs" and which are responsible for its elastic behavior. The linkages between the chains are not equally strong at all points so that when the dough is extended some of them break almost immediately causing permanent deformation of flow, while others remain intact and maintain the rigid structure of the dough. "All of these adjustments in the protein network have to take place in the presence of a starch-water mixture which, although primarily fluid, also possesses some rigid properties, thus complicating the situation, making impossible the complete relaxation of even those protein units which are capable of truly elastic recovery."

Swanson (1938A) explained the phenomenon of gluten formation in wheat flour doughs as related to the hydration of the gluten molecules. When flour is first wetted with water, the protein particles are arranged in a heterogeneous fashion. The action of the mixers tends to orient the gluten particles in a parallel arrangement. Where there is a pulling action on the dough as in the case of commercial high-speed mixers or in a recording mixer, the protein strands become arranged into a more-or-less parallel position. When this point is reached the dough acquires a smoothness which indicates to the baker that the extent of mixing is adequate (Fig. 1). At this stage of mixing, the dough exhibits maximum resistance to pull and the greatest degree of elasticity because the greatest number of gluten coils or springs are in a position to resist elongation on the one hand and to straighten back after elongation on the other. Mixing beyond this stage breaks down the dough causing it to become soft and sticky. If the dough has not been too greatly overmixed, it will recover its strength if allowed to rest. These observations

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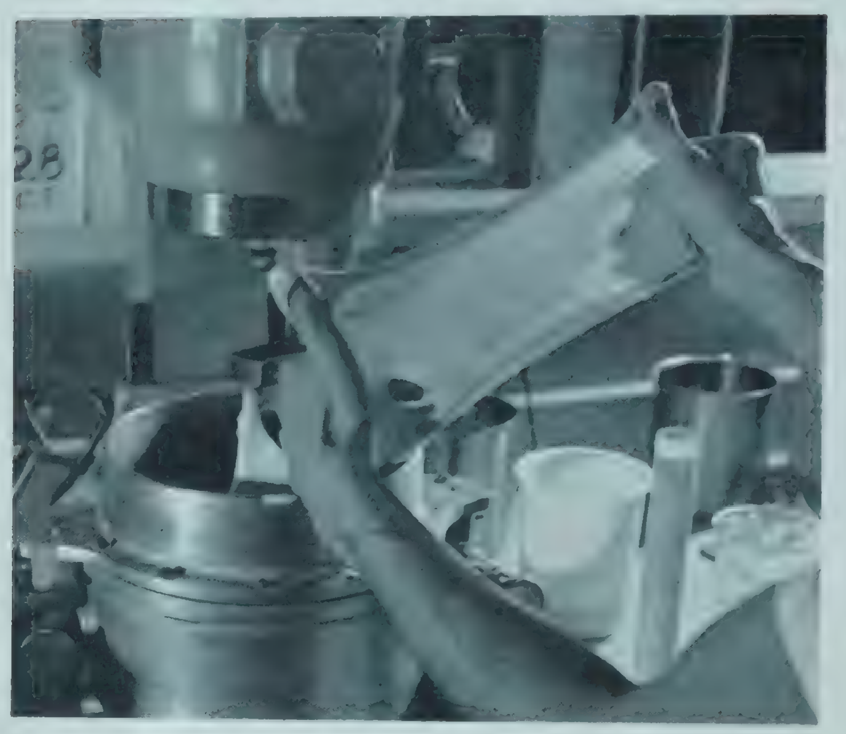


FIG. 1. PROPERLY DEVELOPED STRONG WHEAT FLOUR DOUGH SHOWING ELASTICITY OF GLUTEN

are said to be due to each gluten filament being surrounded by a water film as a result of over-mixing. Such over-mixed doughs will stick to surfaces through this water film because the forces which hold these filaments together are the same forces which attract the water to other surfaces.

Doughs from different flours require different amounts of mixing to develop them to a satisfactory degree. This is explained by differences in the rates at which the water in the dough combines with, or hydrates, the gluten. There may also be differences in the configuration of molecular structure and the way in which the protein particles are bound together in the gluten strands.

Baker and Mize (1941) studied the origin of gas cells in the doughs and considered five hypothetical sources of gas cells as follows: (1) the gas cells in the endosperm particles are incorporated in the dough, (2) the gas voids between the endosperm particles are incorporated in the dough; (3) the mixing beats gas into the dough and subdivides it to produce gas cells of small size; (4) the gas pressure caused by the yeast will originate new cells around the organism; and (5) the work applied to the dough after it is mixed, such as folding, punching, rolling, moulding, and twisting, subdivides gas particles to increase their number

Each hypothetical source of gas cells was considered further by studying a series of doughs in vacuum. On the basis of this work it was concluded that the yeasts themselves are incapable of originating gas cells in doughs but furnish dissolved gas which diffuses into cells formed from air beaten into doughs during the mixing operation. Baker (1941) separated intact gas cells from dough as thin translucent protein bubbles by diluting doughs with brine. The cell wall material was found to be glutinous in character and to consist of about 45 per cent protein and 25 per cent starch on the dry basis.

From observations on fermenting doughs, Baker noted that there was a tendency for the starch and gluten to separate during fermentation and for the gluten to form into transparent cells. This led him to conclude that the starch in flour is not necessary for cell formation in doughs. Baker further stated that "this film is drawn to the surface because the gas nucleus from which the bubbles originated is a glutinous core. As the bubble was expanding the required amount of gluten to satisfy its surface needs was drawn from the starch-gluten matrix of the endosperm material. The properties that enabled this to occur may be controlled by the viscosity and fluidity of the gluten and the amount of adhesion of the gluten to starch."

In the light of the above observations, the importance of intensive mixing of cake batter is emphasized because vigorous mixing action will incorporate minute air bubbles into the batter which can later expand during baking into the fine cells necessary for proper texture in the finished cake. The quantity of gas necessary for expansion could come from several sources, including chemical leavening used in the batter, from steam developed during baking, or from the expansion of the occluded air bubbles themselves at baking temperature.

Types of Wheat

Commercial wheats vary widely in properties depending on the variety and area where grown. They may be loosely grouped into two general headings as hard and soft. The hard wheats include hard spring, hard winter, and durum.

The hard spring and hard winter wheats are the types most desirable for bread production. They mill well and yield good quantities of flour that is high in good quality protein, from which strong, elastic doughs can be made with proper development. These doughs have good tolerance to bakeshop conditions with respect to mixing, fermentation, temperature, etc., and have excellent gas-holding properties and will yield bread with good volume, grain, and texture under a wide range of conditions. The hard wheat doughs have high water-absorptive capacity and generally have excellent dough-handling properties when properly matured. The hard spring and hard winter wheats comprise about 70 per cent of the annual acreage sown to wheat in the United States, as shown by Table 1 (Clark and Quisenberry 1944).

Table 1

DISTRIBUTION OF PRINCIPAL WHEAT CLASSES

Class	Total Wheat Area Occupied, Per cent							
	1919	1924	1929	1934	1939	1944	1939, Acres	1944, Acres
Hard red spring	24.2	22.4	22.0	23.2	20.9	24.0	13,330,648	15,765,582
Durum[1]	6.4	8.2	9.4	4.6	5.3	3.3	3,872,405	2,179,258
Hard red winter	32.0	41.4	43.5	44.6	47.6	46.8	30,456,919	30,709,456
Soft red winter	30.1	22.1	17.7	20.9	19.6	18.2	12,552,634	11,937,179
White	7.3	5.9	7.4	6.7	6.6	7.7	4,198,394	5,092,525
Total	100.0	100.0	100.0	100.0	100.0	100.0	63,911,000	65,684,000

[1] Includes durum and red durum classes.

Durum wheat is produced principally in two varieties, amber durum which is used chiefly in making alimentary pastes such as macaroni, spaghetti, noodles, etc.; and red durum, which has very little value for milling and is used principally as a poultry and livestock feed.

Table 2

QUALITY MEASURES ON VARIETIES IN THE DIFFERENT CLASSES OF WHEAT

Class	No. of Samples	Test Wt. Cleaned Wheat, Lbs.	Protein in Wheat, Per cent	Yield Straight Flour, Per cent	Ash in Straight Flour, Per cent	Water Absorption, Per cent	Loaf Volume, C.C.	Texture, Per cent
Hard red spring	1128	58.5	13.9	69.6	0.49	59.9	2210	89.5
Durum	387	60.3	15.5	71.1	0.77	62.4	1943	89.5
Hard red winter	334	61.1	13.5	72.4	0.45	61.1	2028	89.5
Soft red winter	187	60.5	11.3	71.0	0.46	56.1	1929	87.7
White wheat	511	60.1	12.3	70.6	0.47	57.2	1876	86.9

The soft wheats include soft red and soft white wheats grown principally in Ohio, Missouri, Indiana, Illinois, Pennsylvania, New York, and Michigan, and the Pacific Northwest. These wheats comprise about 20 per cent of the total acreage grown in the United States and are used principally in the production of flour for cakes, pastries, cookies, etc. They are characterized, for the most part, as being low in protein and they yield flours which have low water-absorption capacity and poor tolerance to mixing and fermentation in bake shop practice. They handle poorly in bread baking equipment. They are generally considered undesirable for commercial bread production but are highly desirable for the production of cakes, pastries, and cookies.

Schellenberger and Clark (1924) reported milling and baking results on a large number of samples of several varieties (Table 2). It will be seen that the hard red spring and winter wheats rated highest in loaf volume, while the soft wheat rated lowest. The hard wheats all rated higher in absorption than the soft wheats, with durum rating the highest.

Flours of Different Extraction

In the gradual reduction system of milling the flour comes off the various stages of reduction in different quality, becoming progressively poorer in color and baking quality and higher in ash as the stocks flow down the mill. While the composition and proportion of the individual streams will vary considerably with the length and flow of the milling system, the type of grain being processed, and the technique of the individual miller, Table 3 shows stream percentage and analytical data of a typical flow on a hard winter wheat mix.

It will be seen that in this particular flow, with five breaks and six reductions, the ash content ranged from a low value of 0.38 per cent on

TABLE 3

FLOUR PERCENTAGES AND STREAM ANALYSES FOR MILL PROCESSING HARD WINTER WHEAT MIX

Test Weight 60.5 lbs./bu.

Stream	Moisture	Ash	Protein	Per cent of Total Flour
		(at 14 Per cent Moisture)		
1st Break	15.7	0.48	11.80	2.7
2nd Break	15.8	0.43	12.90	2.9
3rd Break	15.3	0.48	14.90	1.4
4th Break	15.2	0.59	17.00	2.7
5th Break	14.4	0.69	17.00	1.9
Break cuts	15.8	0.45	13.90	5.1
1st Midds	14.5	0.38	11.50	30.2
2nd Midds	14.1	0.38	11.20	23.3
3rd Midds	13.3	0.40	10.90	5.6
4th Midds	12.9	0.46	12.40	3.8
5th Midds	11.8	0.65	13.10	2.0
6th Midds	12.7	0.69	14.10	1.6
Sizings	14.9	0.40	11.10	5.8
Quality	13.8	0.56	11.70	2.6
1st Tailings	13.8	0.69	14.10	1.3
2nd Tailings	14.0	0.73	15.60	1.3
3rd Tailings	13.8	0.95	14.90	4.0
1st Low grade	12.7	0.99	14.30	0.60
2nd Low grade	12.2	1.55	15.20	0.60
3rd Low grade	11.2	2.44	16.90	0.60
Wheat to rolls	15.9	1.53	12.80	

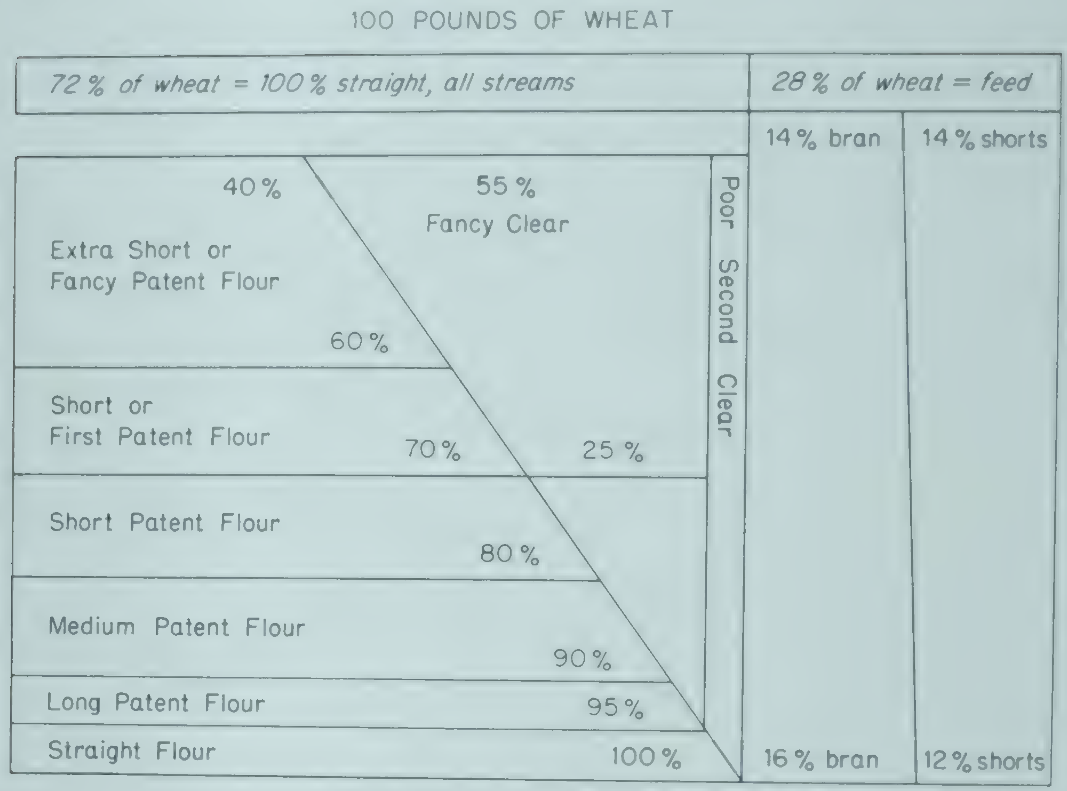

100 POUNDS OF WHEAT
72 % of wheat = 100 % straight, all streams
28 % of wheat = feed
14 % bran
14 % shorts
40 %
55 %
Fancy Clear
Extra Short or
Fancy Patent Flour
Poor Second Clear
60 %
Short or
First Patent Flour
70 %
25 %
Short Patent Flour
80 %
Medium Patent Flour
90 %
Long Patent Flour
95 %
Straight Flour
100 %
16 % bran
12 % shorts

Diagram by Dr. C. O. Swanson, Courtesy of Burgess Publishing Co.

FIG. 2. CHART SHOWING RELATIONSHIPS OF FLOUR GRADES

1st and 2nd midds to a high of 2.44 per cent on low grade. Protein likewise varied widely, running 12.80 per cent in the wheat and from 11.10 per cent in the sizings flour to 17.00 per cent in the 4th and 5th break flour. The percentage of the streams also varied, with 1st midds being the largest with 30.2 per cent and the 1st, 2nd, and 3rd low grade streams the smallest each with 0.6 per cent of the flour. Each of the nine streams, 3rd and 5th break, 5th and 6th midds, 1st and 2nd tailings, and 1st, 2nd, and 3rd low grade, were less than 2 per cent of the flour.

The baking properties of these streams likewise varies widely. However, the individual streams are not used as such in commercial operations, but are combined to make the various grades of flour. The lower ash streams are customarily combined to produce short extraction, or what is termed in the milling industry "short patent" flour, which may amount to from 35 per cent to 60 per cent of the flour. Additional streams may be incorporated into the short patent portions to make a longer extraction, or patent, flour with the remainder classed as fancy clears; or all streams may be combined to produce a "straight grade" flour.

In some instances several grades of flour are produced simultaneously, such as a short patent grade from the lower ash streams, a middle grade from the intermediate quality streams, a first clear from the poorer streams, and a second clear from the remainder.

A schematic diagram (Fig. 2) prepared by Swanson (1938B) shows the proportions of the various flour grades and of feeds which may be produced simultaneously from wheat.

The composition of these grades will vary widely depending on the percentage of the total flour and streams which make them up and with the types of wheat from which they are made, as is shown in Table 4.

TABLE 4

COMPARATIVE COMPOSITION OF WHEAT AND FLOUR GRADES

Type of Wheat	Protein Content of Wheat at 14 Per cent Moisture	Grade of Flour	Per cent Extraction of Flour Based on Wheat	Per cent Ash in Flour at 14 Per cent Moisture	Per cent Protein in Flour at 14 Per cent Moisture
Soft red	9.80	Straight	72	0.38	8.20
		Short patent	35	0.30	7.50
		Bakers patent	65	0.34	7.90
		Clear	10	0.68	9.90
Hard spring	13.50	Straight	72	0.47	12.90
		Short patent	35	0.39	12.00
		Medium patent	60	0.41	12.20
		Long patent	65	0.43	12.50
		First clear	10	0.70	15.50
		Second clear	4	1.20	16.50
Hard winter	12.90	Straight	72	0.47	12.10
		Medium patent	60	0.41	11.70
		Long patent	68	0.45	12.00
		Second clear	4	1.20	16.00

It will be seen that the ash content for the straight grade soft at 72 per cent extraction runs 0.38 per cent while the straight grade from hard spring at approximately the same extraction ran 0.47 per cent ash at 14.0 per cent moisture. The protein contents of the various wheats also were vastly different, with soft red, hard spring, and hard winter running 9.80, 13.50, and 12.90 per cent respectively. The protein content of the wheats, as well as the protein and ash contents of the flour, will vary somewhat from season to season, depending on growing conditions.

Table 5 illustrates the variation which can be encountered in wheat samples. In this study nine samples of Bison wheat representing the 1958 crop were obtained from certified seed growers in the state of Kansas. Samples were taken from different soil areas as judged by a Kansas State Soil map, and analyzed for ash and protein. A portion of each was tempered to 16 per cent moisture and milled on a Buhler mill. It will be seen that the protein content of the wheat ranged from 10.6 per cent to 14.7 per cent and the ash content of the flour ranged from

TABLE 5

CHEMICAL AND PHYSICAL DATA ON SAMPLES OF BISON WHEAT AND FLOUR MADE FROM THEM

	Wheat		Flour									
	at 14 Per cent Moisture		at 14 Per cent Moisture		Farinograph Data							
Sample Origin[1]	Ash	Protein	Ash	Protein	Abs.	I	M	R	D	Drop 30 Units	Valorimeter	Buhler Mill Extraction Per cent
Marysville, Kansas Soil Area—4	1.58	14.2	0.33	12.8	58.0	8.0	12	...	..	...	..	68.7
Mostly thin rocky soils good for bluestem and associated grasses. Many pastures have been overgrazed. Getting enough land to go with pasture is a problem that has caused too much land suitable only for grasses to be cultivated.												
Caldwell, Kansas Soil Area—12	1.64	10.6	0.34	9.2	61.9	1.0	15	16	35	11	87	66.2
The dark clay and clay-pan residual soils of this area are well adapted to wheat if care is taken to prevent erosion and if fertilizers are applied.												
Chase, Kansas Soil Area—15	1.74	14.7	0.36	13.0	63.6	6.5	12	10.5	40	18.5	81	67.6
These nearly level clay-pan soils have slow permeability which adapts them best to wheat. In years of adequate moisture grain sorghums do well.												
Agra, Kansas Soil Area—17	1.43	11.2	0.33	10.0	64.0	9.0	20	...	..	...	..	64.2
Wheat and sorghum are adapted to these soils with corn in addition in the north one-fourth of the area.												
Kiowa, Kansas Soil Area—19	1.46	12.6	0.33	11.4	63.0	5.0	7.5	6.5	50	11.5	68	63.9
This area has limited cultivated acreage. Pastures contain mud and short grasses where canyons and gulley walls are not too steep.												
St. Francis, Kansas Soil Area—20	1.57	12.7	0.34	11.5	64.1	2.5	4	3	90	6.5	52	65.2
Except for steep slopes adjoint to stream valleys, the nearly level soils of this area are adapted to wheat and sorghum. The Keith soil irrigates well.												
Plains, Kansas Soil Area—25	1.70	11.2	0.38	9.9	59.2	18	20	...	..	...	..	65.5
The soils of this area are finer textured than those of adjoining areas and problems of water-erosion are more serious. Wheat yields well on these soils.												
Moscow, Kansas Soil Area—26	1.86	14.7	0.39	13.2	67.0	11.5	15.5	...	..	...	..	65.2
These sandy land soils are susceptible to wind erosion and need native grasses to protect them. Many cultivated areas have suffered severe wind erosion.												
Tribune, Kansas Soil Area—27	1.57	12.2	0.37	11.4	65.4	4.0	7.0	6	50	10.5	66	66.3
Except for receiving less rainfall, the soils of the area are similar agriculturally to Area 25.												

[1] Information on soil areas from Kansas Agricultural Bulletin 392, August 1957, Kansas State College of Agriculture and Applied Science, Manhattan, Kansas.

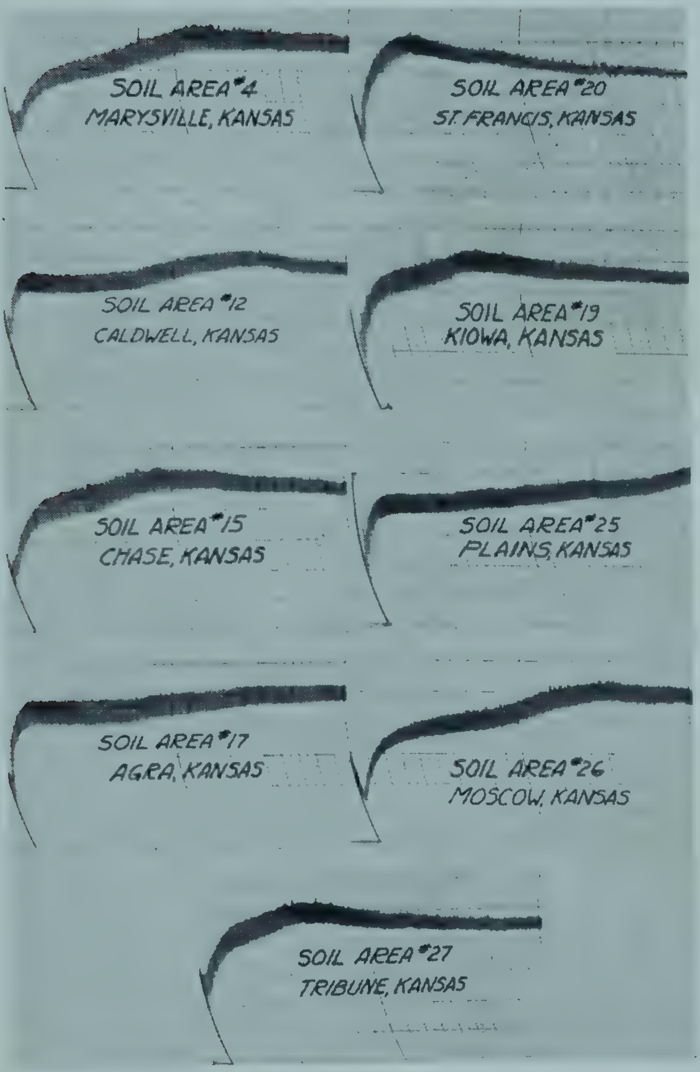


Fig. 3. Farinograph Charts for Flour Milled from Samples of Bison Wheat Grown in Various Kansas Soil Areas

0.33 per cent at 68.7 per cent extraction to 0.39 per cent at 65.2 per cent extraction. The protein content of the flour likewise varied over a wide range, the lowest being 9.2 per cent from the sample of wheat which ran 10.6 per cent protein and the highest being 13.2 per cent from the highest protein sample of wheat which ran 14.7 per cent. Mixing time, as measured by the farinograph, ranged from 4 minutes to 20 minutes and absorption from 48.0 per cent to 67.0 per cent. Fig. 3 shows the farinograph curves identified by area number and location. Since these samples were all grown under the close supervision necessary for production of certified seed, the extreme variation shown in these various samples must be due to agronomic and climatic factors.

The Composition of Flour

The composition of flour varies with the wheat variety and the grade as well as the conditions under which the grain was grown. The overall analysis of all types and grades will range approximately as shown in Table 6. While the protein content is of greatest importance from a bread baking standpoint, the other constituents also play an important role.

Table 6

THE COMPOSITION OF WHEAT FLOURS

	Minimum, Per cent	Maximum, Per cent
Protein	7.5	15.0
Ash	0.30	1.0
Fat	1.0	1.5
Fiber	0.4	0.5
Carbohydrates as starch	68.0	76.0

Flour Proteins.—The proteins in wheat are reported by Osborne (1907) to consist of approximately equal amounts of glutenin and gliadin, with about 20 per cent of the protein consisting of leucosin, an albumin; edestin, a globulin; and a small amount of proteose. These last three proteins are classed as the non-gluten proteins which are soluble in either water or dilute salt solution. The insoluble, or gluten, portion, which consists of glutenin and gliadin, is largely responsible for the elastic properties of flour doughs. The glutenin portion is said to give

Table 7

AMINO ACID COMPOSITION OF GLUTEN PROTEINS

	Gluten, Per cent	Gliadin, Per cent	Glutenin, Per cent
Arginine	4.3	3.2	4.7
Lysine	2.1	0.6	1.9
Histidine	2.4	2.1	1.8
Tyrosine	4.2	3.1	5.1
Tryptophane	1.1	0.9	1.8
Phenylalanine	2.0	2.5	2.0
Cystine	1.9	2.3	1.7
Methionine	3.3	2.3	..
Serine	..	0.1	0.7
Threonine	2.5	3.0	..
Leucine and isoleucine	6.0	6.0	6.0
Valine	3.0	3.0	1.0
Glutamic acid	36.0	46.0	27.2
Aspartic acid	..	1.4	2.1
Glycine	..	1.0	1.0
Alanine	5.5	2.5	4.4
Proline	11.0	13.2	4.4
Hydroxyproline		..	..
Ammonia	4.5	5.1	4.0

strength and firmness to the gluten, while the gliadin adheres to the glutenin and holds it together. The gliadin can be separated from gluten by dissolving in 70 per cent alcohol with glutenin remaining undissolved.

Grewe and Bailey (1927) demonstrated that there is no consistent relationship between the proportion of the gliadin in flour and its baking quality. The evidence seems to be that the gliadin and glutenin obtained from different wheats have the same chemical composition and Blish (1946) reported the amino acid composition of gluten and its fractions, as indicated by Table 7.

McCalla and Gralen (1942) studied the fractionation of gluten in sodium salicylate dispersions by means of sedimentation velocities, sedimentation equilibria, and diffusion measurements. They have come to the conclusion that the material identified as "gluten," which was thought to consist of gliadin and glutenin, is really not two protein fractions at all, but a wide mixture of proteins of varying molecular size. This material can be separated into a great many fractions which differ progressively and systematically in both physical and chemical properties.

The Carbohydrates of Wheat Flours.—The carbohydrates of wheat flours consist largely of starch with small amounts of dextrins and sugars, cellulose or fiber, and gums. Koch *et al.* (1951), using paper chromatography on aqueous extracts of bakers' patent flour, confirmed the presence of the following sugars: glucose, 0.01 per cent; fructose, 0.02 per cent; sucrose, 0.10 per cent; maltose, 0.08 per cent; melibiose, 0.18 per cent; and raffinose, 0.07 per cent.

Fats and Lipids in Wheat Flours.—Patent grades of flour contain about one per cent of petroleum ether soluble materials with lower grades containing somewhat more. Sullivan and Howe (1938) found the petroleum ether extract of wheat flour to amount to 1.38 per cent on the dry basis.

The percentages of the fatty acids were computed from the lipid contents of the petroleum ether extract of the flour and ran as follows:

	Percentage
Total saturated acids (83 per cent palmitic)	15.6
α linolenic acid	0.84
β linolenic acid	2.96
α linoleic acid	25.49
β linoleic acid	20.51
Oleic acid (by difference)	34.60

The keeping quality of the flour is related to its fat content and in over-aged flour the fatty acid content increases due to hydrolysis of the fatty esters.

Ash Content.—Flour contains from 0.3 per cent to 1 per cent ash, depending on its grade. The mineral constituents of wheat are presented in Table 8 as reported by Sullivan and Near (1927).

As the flours are milled they are treated appropriately with bleaching and maturing agents or with enzyme supplementation in the various grades for the use for which they are intended. These various grades of flours from the different types of wheat have widely different uses and Harrel (1959) has classified them according to their usage. (See Tables 9 and 10).

Table 8

MINERAL CONTENT OF WHEAT AND MILL PRODUCTS CALCULATED AS THE ELEMENTS FROM ANALYSIS OF THE ASH[1]

	In Parts per Million of Product, on Dry Basis						
Element	Wheat	Patent Flour	Clear Flour	Low-grade Flour	Total Mill-run Middlings	Bran	Germ
Total ash	20,500	4,820	8,040	14,620	47,620	67,480	50,410
Magnesium	1,898	308	624	1,327	4,546	7,166	3,801
Calcium	452	180	227	376	1,115	1,158	692
Phosphorus	4,440	1,162	1,910	3,511	10,446	15,208	12,533
Potassium	2,370	552	875	1,553	5,633	7,098	5,542
Zinc	100	40	48	129	319	562	420
Iron	31	8	11	22	71	95	68
Manganese	24	2	5	12	48	112	67
Copper	6	2	2	4	13	14	9
Aluminum	3	0.6	2	7	8	27	25

[1] From Sullivan and Near (1927).

Table 9

COMPOSITION AND USES OF HARD SPRING WHEAT FLOURS

Protein, Per cent	Ash, Per cent	Bakery Products in Which the Flour Is Used
12.5 to 12.8	0.42 to 0.44	White pan bread (both sponge and straight dough). Specialty and variety breads. Hamburger and wiener rolls. Yeast raised sweet goods. Soft rolls (Parker House type). Doughnuts, yeast raised. Hard rolls and hearth bread.
12.8 to 13.1	0.46 to 0.48	White pan bread (both sponge and straight dough). Hard rolls and hearth bread. Specialty and variety breads.
13.5	0.48	Hard rolls and hearth bread. Blender flour for coarse flour breads.
15.0	0.48	High gluten flour for Kaiser rolls. Italian, French and Jewish hearth breads.
15.0 to 15.5	0.70 to 0.74	Carrier flour used in making whole wheat, rye, specialty and variety breads. Blender flour used in mixes with rye flour for rye bread.

TABLE 10

COMPOSITION AND USES OF HARD WINTER WHEAT FLOURS

Protein, Per cent	Ash, Per cent	Bakery Products in Which the Flour Is Used
12.25 to 12.50	0.42 to 0.44	White pan bread, both sponge and straight doughs. Hamburger and wiener rolls. Soft rolls (Parker House type). Specialty and variety breads. Yeast raised sweet goods and doughnuts.
12.50 to 13.0	0.46 to 0.48	White pan bread, both sponge and straight doughs. Blender flour in some variety and specialty breads and rolls. Blender flour for chemically leavened biscuits, and muffin and waffle mixes. Heavy fruit cake mixes.
15.00 to 15.50	0.70 to 0.74	Carrier flour used in making rye, whole wheat, specialty and variety breads. Blender flour for baking powder doughnuts, and muffins and waffle mixes.

The hard spring grades with a protein range of from 12.5 per cent to 12.8 per cent are used principally in bread, hamburger buns, soft rolls, etc., and are generally known as bakers' patents. The higher protein spring straight grades, at about 12.8 per cent to 13.1 per cent protein, are used for Kaiser rolls, etc., and the spring clear grades are used principally to carry rye flour for rye bread. Winter wheat flour patent grades are used in bread baking and buns. The soft wheat flours are used in cake and pastry products.

Air-Separated Flour

Within the last few years air-separation techniques have been developed to the extent that they can be used to fractionate flour into cuts of widely different composition. For example, data have been reported by Elias and Scott (1957) on the separation of a soft wheat flour of ten per cent protein content and 0 to 100 micron particle size. After reducing the particle size to approximately 0 to 75 microns by use of a specialized impact grinding technique, 20 per cent of the flour can be recovered at a protein content of 20.0 per cent. The remaining 80 per cent will have a protein content of about eight per cent, with the majority of the particles being in the size range of 15 to 75 microns.

The fine material has good bread baking properties and its use for fortifying bread flours is suggested.

Hard wheat flour can be similarly separated to yield 15 per cent fine cut at 0 to 15 micron size and 20 per cent protein, and 85 per cent coarse cut at 9.4 per cent protein, starting with a sample of eleven per cent protein content.

Re-grinding and re-separating the coarse portion, an additional fine cut can be obtained at seven per cent protein and a coarse cut at ten per cent protein.

The fine fraction from the re-separation has good cake baking properties while the fine material from the first separation can be combined with the coarse material from the second separation for bread flour.

The range of possibilities of air-separation is further illustrated by Wichser (1958) wherein he shows that fractions with protein contents ranging from 3.0 to 20.0 per cent can be obtained from soft wheat flour.

Bleaching and Maturing of Wheat Flour

Freshly milled flour has a slightly yellowish color which is considered undesirable by some and doughs made from it are likely to be unduly sticky and do not handle or bake well. Treatment with small amounts of certain chemicals will both lighten the color of the flour and improve its baking quality. Generally it is considered that this represents two entirely different types of treatment (1) bleaching of the carotenoid pigments in the flour and (2) chemically modifying the gluten.

For the bleaching of flour benzoyl peroxide is most widely used. It is added as a powder in a blend with suitable diluting and stabilizing agents by the use of precise chemical feeders. Proportions of benzoyl peroxide commonly used are one pound of 32 per cent benzoyl peroxide to from 40 to 120 hundredweight of flour. Nitrogen peroxide made by passing air through an electric arc is also used to some extent as a bleaching agent. It is, however, not as effective for color removal as benzoyl peroxide and flours bleached to a maximum degree of whiteness with nitrogen peroixde can be still further bleached when benzoyl peroxide is added.

Certain enzyme preparations may also be used in flour bleaching. Soy beans contain a substantial amount of the enzyme lipoxidase which is capable of oxidizing flour carotenoids to colorless compounds under suitable environmental conditions. A fraction from soy beans high in lipoxidase is a patented additive sold commercially for whitening doughs (Renner and Haas 1939). The manufacturers of this product recommend its use in flours as the doughs are made up, claiming bleaching and flour improving action superior to chemical methods.

Under the category of maturing agents are included such materials as chlorine dioxide, chlorine gas plus a small amount of nitrosyl chloride, nitrogen trichloride, potassium bromate, potassium iodate, ammonium persulfate, and ascorbic acid. Government regulations generally control the additions of these materials. (The United States government regulations permit only the use of the oxides of nitrogen, chlorine, nitrosyl chloride, chlorine dioxide, and potassium bromate in flour.)

The preferred treatment for bread flours is generally benzoyl peroxide for bleaching and chlorine dioxide for maturing treatment. Potassium bromate is frequently added in small amounts, depending on the type of flour and the baking procedure for which it is to be used, with proportions as high as 50 parts per million being used in certain types of long fermentation bread doughs. Nitrogen trichloride has been reported (Mellanby 1946) to cause running fits in dogs when fed in a diet high in heavily nitrogen trichloride treated gluten and its use has been discontinued even though Elvehjem (1948) showed rather conclusively that no deleterious effects could be detected in humans even at rates approximately 20 times normal intake.

The action of bleaching and maturing agents is vastly different. The bleaching agents exert their action on the carotenoid pigments of the flour. Benzoyl peroxide acts slowly after addition to the flour and requires several hours to decompose and exert its full bleaching action. Chlorine dioxide, which is a gas, acts on the flour almost instantly on application and its effect will be noted in slight improvement of color and in better handling properties of the dough and in the loaf volume of the finished product. The amount of chlorine dioxide that is added, however, is generally so small that its bleaching action is slight. Potassium bromate may be added to flour as a dry solid at the mill as the flour is produced or incorporated in a dough conditioner to be added by the baker. Potassium bromate is without action in the dry flour and remains inert in the flour or dough until sufficient acid is produced by fermentation of the dough to start its decomposition. Chlorine gas which functions both as a bleach and an improver is used extensively in cake flour for pH adjustment to improve cake baking properties.

The maturing action of oxidizing agents on doughs has been investigated by Jørgenson (1939) and their action attributed by him to their inhibiting properties on the proteolytic enzymes present in the flour. Jørgenson attributes the green characteristics of doughs made from untreated flours to the action of the proteolytic enzymes. By adding oxidizing agents to flour or to the dough, the proteolytic activity can be reduced and the handling characteristics of the resulting product improved. Froelich and Frey (1939) found that the effects obtained by bromate were far more extensive than mere protease inhibition. They obtained an effect similar to the bromate effect by mixing dough in oxygen and expressed the belief that the beneficial result is attributable to the action of oxygen on some flour constituents other than the enzymes.

If too much bromate is added a poor loaf results. This can be corrected by remixing the dough after fermentation; if the remixing is too extensive, however, the dough breaks down and a poor loaf results. The relation-

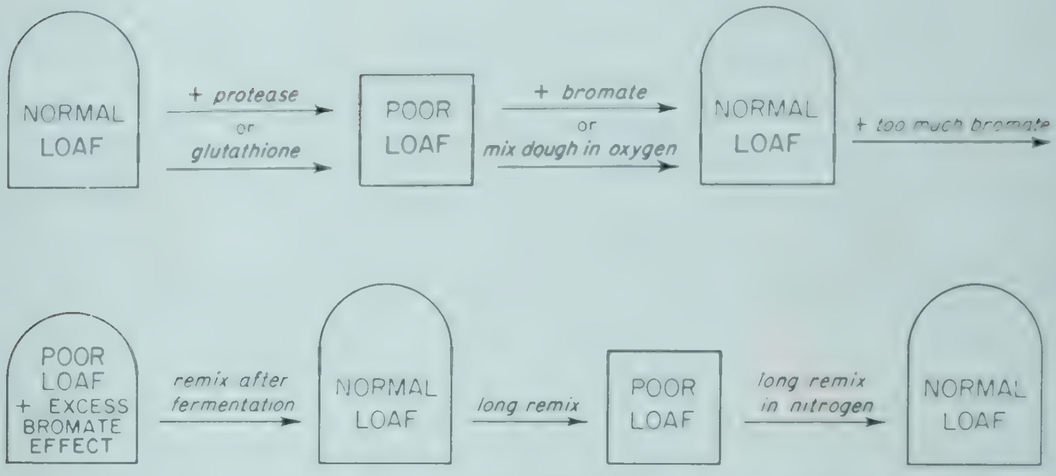

NORMAL LOAF
+ protease
or
glutathione
POOR LOAF
+ bromate
or
mix dough in oxygen
NORMAL LOAF
+ too much bromate
POOR LOAF + EXCESS BROMATE EFFECT
remix after fermentation
NORMAL LOAF
long remix
POOR LOAF
long remix in nitrogen
NORMAL LOAF

Fig. 4. Interrelationships of Oxidation Effects in Dough

ships or functions of the various oxidizing agents or reducing agents in the maturing of flour were described by Froelich and Frey (see Fig. 4).

Sullivan *et al* (1940) suggest that these maturing agents act on sulfhydryl (S—H groups) in the gluten proten, oxidizing them to form $R(SO_2)R$, RSO_3H, R—S—H, etc., and such reactions are responsible for the change in physical characteristics of certain doughs and the improvement gained by use of oxidizing agents or oxidation systems.

RYE FLOUR

Rye flour is produced in a milling process very similar to that used for producing wheat flour. The grain is cleaned on conventional cleaning equipment to remove foreign materials; it is then washed and tempered to suitable moisture content, generally about 15.5 per cent, and held for a time to allow the water to penetrate the kernels. It is then milled on a gradual reduction system consisting of rolls and sifters.

The rye endosperm is soft and does not break out in sharp chunks as does wheat, so purifiers are not customarily used.

Rye flour is produced in a number of grades as required by the baker. These are characterized largely by color, such as White, Light, Medium, etc., rather than by ash and protein content, although ash and protein content are in a general way an indication of rye flour quality.

Tables 11, 12, and 13 show the composition of some of the various grades of rye flour (Larsen 1959).

Rye flour protein is reported by Kent-Jones and Amos (1947) to have the following composition:

Gliadin	42 per cent
Glutenin	42 per cent
Globulin	8 per cent
Albumin	8 per cent

TABLE 11

SPECIFICATIONS FOR WHITE RYE FLOUR

Type of Measurement	Test Used	Values	Units of Measurement
Moisture	Air oven	14.5 Maximum	Per cent
Ash	Muffle oven	0.58–0.78	Per cent
Color	Pekar	White	Comparison
Protein	Kjeldahl	7.0–9.1	Per cent

TABLE 12

SPECIFICATIONS FOR MEDIUM RYE FLOUR

Type of Measurement	Test Used	Values	Units of Measurement
Moisture	Air oven	14.5 Maximum	Per cent
Ash	Muffle oven	1.11–1.39	Per cent
Color	Pekar	Medium white	Comparison
Protein	Kjeldahl	10.1–12.8	Per cent

TABLE 13

SPECIFICATIONS FOR DARK RYE FLOUR

Type of Measurement	Test Used	Values	Units of Measurement
Moisture	Air oven	14.5 Maximum	Per cent
Ash	Muffle oven	2.05–2.83	Per cent
Color	Pekar	Dark	Comparison
Protein	Kjeldahl	13.7–16.2	Per cent

This is substantially the same as for wheat flour protein; however, rye flour doughs are characteristically very weak and cannot be washed to separate gluten from them. Schulerud (1939) has found that rye flours contain gummy substances two per cent of which when added to wheat flour will prevent formation of a dough when washing gluten. Jacobs (1944) shows how such gummy substances can prevent satisfactory washing of rye-wheat flour mixtures.

While in some areas of the world, notably Germany, Poland, and Russia, rye flour is used alone for bread baking, in American baking processes it is used with strong flours generally in proportion of 20 to 40 per cent rye flour to 60 to 80 per cent high protein clear flour for such products as American-type rye bread, Jewish sour rye bread, etc.

Another product made from rye flour is Knäkebrod, a product of Scandinavian origin which is made from 100 per cent rye flour or meal made into a dough and sheeted out and baked. It is generally leavened only by steam during baking although sometimes it is yeasted to produce a lighter and more tender product.

CORN FLOUR

Corn flour is produced by dry milling of corn. Although some small country millers still grind whole corn for corn flour and similar products, the principal dry corn millers now degerm the grain to improve the keeping quality of the finished product as well as to gain increased revenue from the sale of the oil. Briefly, dry corn milling consists of cleaning the corn, tempering a short time by the use of warm water and steaming to about 21 to 23 per cent moisture. The tempered corn is then run through a Beall or similar degerminator to crack the kernels and release the germ. The degermed stocks are then dried to about 15 per cent moisture for further processing to grits, meal, or flour on a series of rolls, sifters, and aspirators.

The principal products of dry corn milling are corn grits or hominy, corn meal, corn flour, corn oil, and corn or hominy feeds. The products of interest to the baking industry include corn meal and corn flour which are used in corn muffins and some breads, for dusting the peel in baking of rye breads and similar uses. A small amount of corn flour may be used as a gelatinized product in bread doughs to help hold moisture and retard staling.

SOY BEAN FLOUR

A limited amount of soy bean flour is used in the baking industry in some instances to give color to the product and in others because of its high nutritive value and ability to supplement the amino acids in wheat flour, since soy flour is notably high in lysine (Hafner 1942) in which wheat flour is somewhat deficient (Table 14).

TABLE 14

NUTRITIVE VALUE OF PROTEIN IN SOY FLOUR AND WHEAT FLOUR

Sole Source of Dietary Protein	Grams Gain Per Gram Protein Eaten[1]	Relative Protein Efficiency, Per cent
Extracted soy flour (low fat)	1.83	100.0[2]
Full fat soy flour	1.70	92.9
Raw soybeans	0.98	53.5
Patent wheat flour[3]	0.71	38.8
Patent wheat flour, enriched[3]	0.66	36.1
Whole wheat flour[3]	1.14	62.3

[1] Nutritive value

[2] Arbitrarily assigned a relative protein efficiency of 100 per cent of its nutritive value of 1.83 g. gain per gram protein eaten.

[3] All three wheat flours were milled from hard spring wheat of similar analysis and origin. The patent flours were commercial runs; the whole wheat was produced by grinding whole wheat in a laboratory mill.

Generally in the baking industry two types of soy bean meal are used, namely high fat and low fat. The high fat type is made from beans prior to extraction, treating them with steam, drying and grinding them to remove hulls, and reducing them to flour. The low fat type is made from meal after solvent extraction to remove the oil. Finney (1946) showed that excellent bread can be made with soy flour up to eight per cent of the flour used by increasing the quantity of potassium bromate used in the formula in accordance with the amount of soy flour added. The change in crumb color as a result of the pigment in the soy flour was not noticeable so far as most of the consumers were concerned when up to four per cent of soy flour was included in the formula.

THE TESTING OF WHEAT FLOUR

The testing of wheat flour can be divided into four categories as follows: (A) chemical tests; (B) physical; (C) organoleptic; and (D) baking tests.

While most of the tests have been established and published by The American Association of Cereal Chemists in the 6th Edition of Cereal Laboratory Methods (Anon. 1957), a brief résumé of each and their significance seems to be in order.

Chemical Methods

Moisture Content.—The moisture content in wheat and flour is of extreme importance from an economic standpoint for the moisture content affects the value of the product. Excessive moisture also adversely affects the keeping quality. In addition, best milling results can be obtained only from properly tempered wheat of optimum moisture content.

A number of techniques for moisture determination are used. Probably the most common is the standard air oven method which consists of drying the sample to constant weight in an air oven at 266°F. Other methods used include the vacuum oven method and various conductivity and capacitance methods.

Ash Content.—The ash content of flour is determined by igniting a weighed quantity of flour in a muffle furnace. In order to speed up the combustion, an alcoholic magnesium acetate solution is added to the tared flour sample prior to ignition.

The ash content has come to indicate quality or grade of flour in that increasing amounts of ash are associated with more bran dust in the flour and hence poorer quality. This is not necessarily true for the ash content in flour is dependent on the type of wheat processed as well as the conditions under which it was grown. Some areas consistently produce wheat which will yield flour of abnormally high ash content and in some years the entire crop tends to run abnormally high in ash, making ash content alone an unreliable guide to flour quality.

Protein Content.—The protein content of wheat and flour is commonly based on total nitrogen determined by the Kjeldahl method but fast methods based on dye absorption are being developed (Udy 1956).

Good gluten quality and consequently good dough characteristics, good loaf volume, and good grain and texture are commonly associated with higher protein content. But protein quality as determined by actual baking results and physical dough tests is of much more value than protein content as a measure of good baking quality.

Crude Gluten Content.—The crude gluten content of flour is commonly determined by working a weighed quantity of flour with a small amount of water into a firm ball and kneading the resulting dough under a gentle stream of water after allowing it to stand and cure for a time. The product so obtained is not pure gluten, but a mixture of starch and gluten and some fibrous material.

As shown by Swanson (1938B) the actual dry substance gluten obtained closely approaches the protein content of the flour itself. This is due to the fact that a rather consistent proportion of the protein material exists in the flour as soluble protein which, although lost in washing, is compensated for in the dry gluten substance by the starch and fiber which remains with the gluten. The gluten test, although still extensively used as an indication of flour quality, is not generally considered highly accurate or a highly reliable means of judging flour quality even though some useful information can be gained from it.

Starch Content.—The starch content of a sample of flour is readily determined by hydrolyzing the sample with dilute acid and determining the sugars by any of the conventional methods. It may also be determined by dissolving the sample in hot calcium chloride solution and determining the starch content polarimetrically after removing the soluble protein by suitable chemical methods. The starch content has comparatively little significance in evaluation of flour quality.

Fat Content.—The fat content of wheat flour is usually determined by petroleum ether extraction of the sample after acidification with dilute hydrochloric acid.

Amylolytic Activity as Measured by Reducing Sugar Content.—The reducing sugar content of flour is determined customarily by the alkaline ferricyanide method which consists of adding an excess of alkaline ferricyanide reagent to a clarified sample of flour extract and titrating the unused ferricyanide with thiosulfate and calculating the reducing sugars. Production of reducing sugars by a flour digested under standard conditions provides a measure of amylolytic activity. This is an extremely important determination in that it is taken as an indication of diastatic activity wherein excessive amounts of reducing sugars could indicate partial germination of the wheat at harvest time or overmalting of the flour.

pH Determination.—The electrometric method is most acceptable for the determination of pH in flour. The actual procedure consists of suspending 10 grams in a dry Ehrlenmeyer flask in 100 ml. of freshly boiled distilled water, allowing the sample to stand for a short time, and then determining the pH electrometrically in a portion of the supernatant liquid. The pH of flour will normally run in the neighborhood of 6.1 to 6.2. If the pH value is lower than this, it is customarily taken as an indication of chlorine treatment in the bleaching process. This treatment is of extreme importance in the control of quality in high ratio cakes where pH value would be expected to fall in the range of 4.6 to 5.0 depending on the characteristics of the wheat being milled.

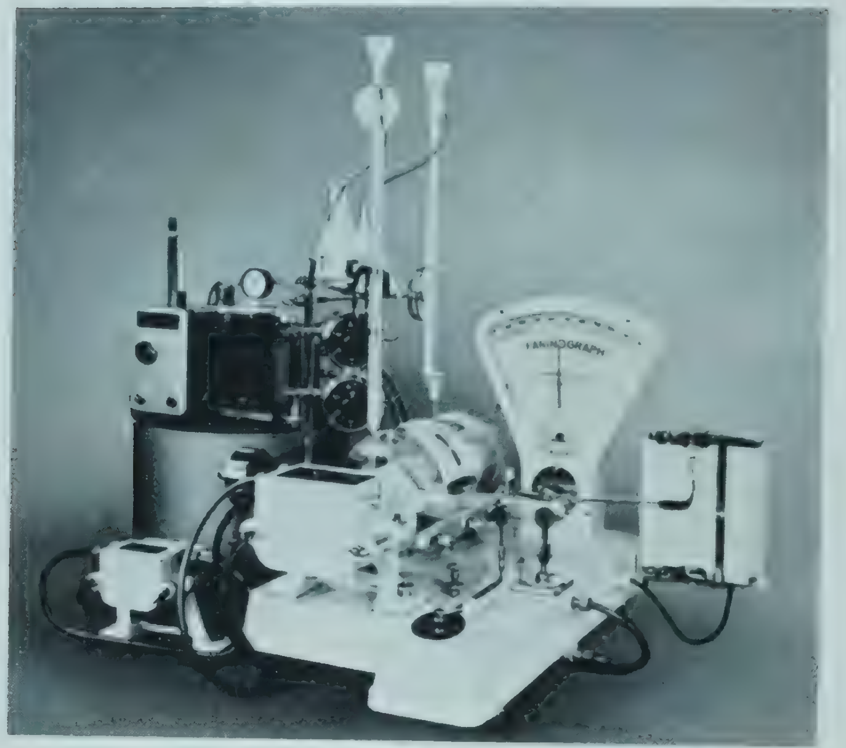
Fat Acidity.—Fat acidity is commonly determined by extracting an aliquot portion of the sample in a Soxhlet or other suitable extractor with petroleum ether and titrating the fatty acid so obtained. The presence of abnormally high proportions of fatty acids is taken as an indication of the flour having been derived from unsound grain or having deteriorated through over-age or poor storage conditions.

Gas Production.—The amount and rate of gas production are used as a means of checking the adequacy of enzyme supplementation in flour. In the procedure generally used, measured quantities of flour, water, and yeast are thoroughly mixed and incubated at carefully controlled temperature in a suitable gas measuring device. The rate and amount of gas released is interpreted as an indication of enzyme activity. Readings of most interest are those taken after the fourth, fifth, and sixth hours of incubation.

Maltose content and Brabender amylograph values are likewise used as an indication of enzyme content.

Particle Size.—With the milling industry becoming interested in fine grinding of flour for air-separation, there is need for quick accurate methods for determining particle size of the flour samples and the percentage of particles of different sizes in samples as a means for controlling process operations. Techniques for determination of particle size in flour samples are not well established but among those being used are the following:

(*a*) ***Andreason Pipette Method*** (Andreason 1929).— This method is based on rate of settling in non-aqueous medium; this is determined by withdrawing aliquots of the suspended sample from the bottom of a settling tube at intervals and determining solids content and calculating particle size from Stokes Law.



Courtesy of C. W. Brabender Instruments Co.

FIG. 5. THE BRABENDER FARINOGRAPH

(b) Whitby (1955A, 1955B) Sedimentation Method.—This method is also based on the rate of settling of the particles in non-aqueous media. The technique is modified somewhat by the use of a centrifuge to speed up rate of settling.

(c) Fischer Particle Size Method (Gooden and Smith 1940).—This method is based on measurement of the rate of gas diffusion through an established quantity of material under constant pressure. Only average particle size data can be obtained by the Fischer method.

Chlorine.—Chlorine is commonly used in the bleaching and maturing of soft wheat flours for cakes and, to a limited extent, on bread flours. Its presence in large amounts can be detected by pH content of the flour, but it is frequently tested for qualitatively by preparing a petroleum ether extract of the flour, which is evaporated to dryness in a small dish, then a portion of the residue left after evaporation is mixed with copper oxide and ignited in a gas flame on a copper wire. Under these conditions, if chlorine is present, a green flame can be observed.

Physical Dough Testing

Because of the extreme importance of the physical dough characteristics of wheat flour doughs in bake shop performance and in bread quality,

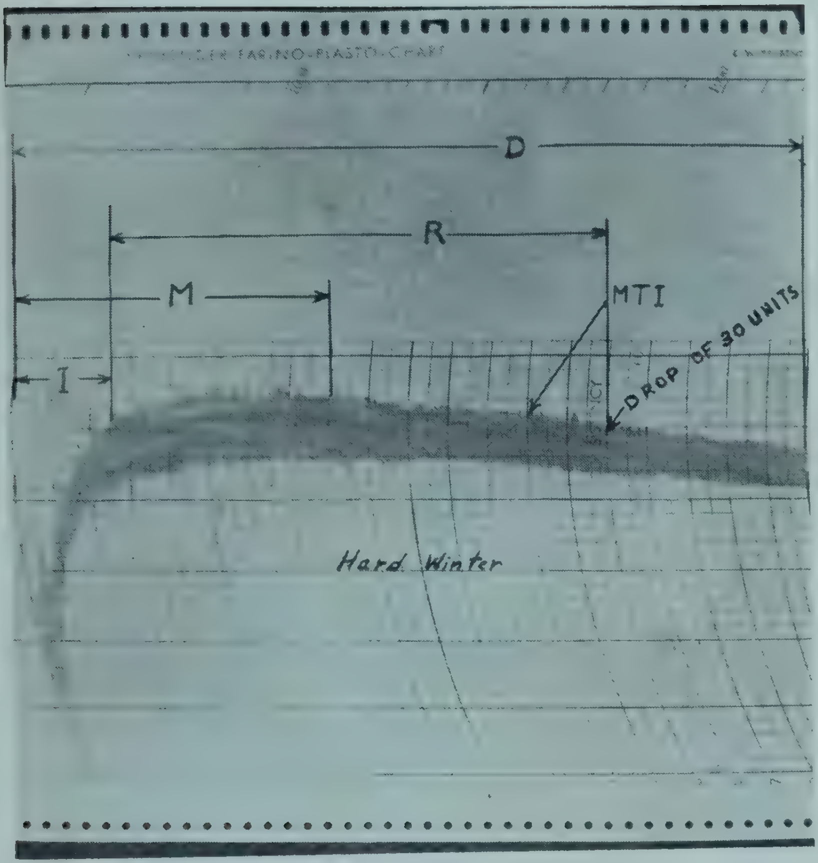


Fig. 6. Farinograph Curve Readings

many efforts have been made to evaluate flour quality in terms of physical measurements on flour doughs to give an indication of their hydration and mixing characteristics. For this purpose numerous devices have been developed. Some of them are equipped with recording devices to provide a continuous record of flour performance during the test.

The **Brabender farinograph** (Fig. 5) is probably the best known and most widely used of the various physical dough testing devices. It consists of a water-jacketed mixer with two helical spiral blades driven by a synchronous constant speed motor. The torque on the mixer arms is measured by a dynamometer equipped with a continuous recording chart. Flour to be tested is placed in the mixing bowl and sufficient water added so that the consistency of the dough is such that the mixing curve centers on the 500 Brabender Unit line at the point of maximum development, thus establishing comparisons between flours at what is presumed to be uniform consistency.

Fig. 6 shows how some of the readings are taken from a farinograph curve. The most important of these are the following:

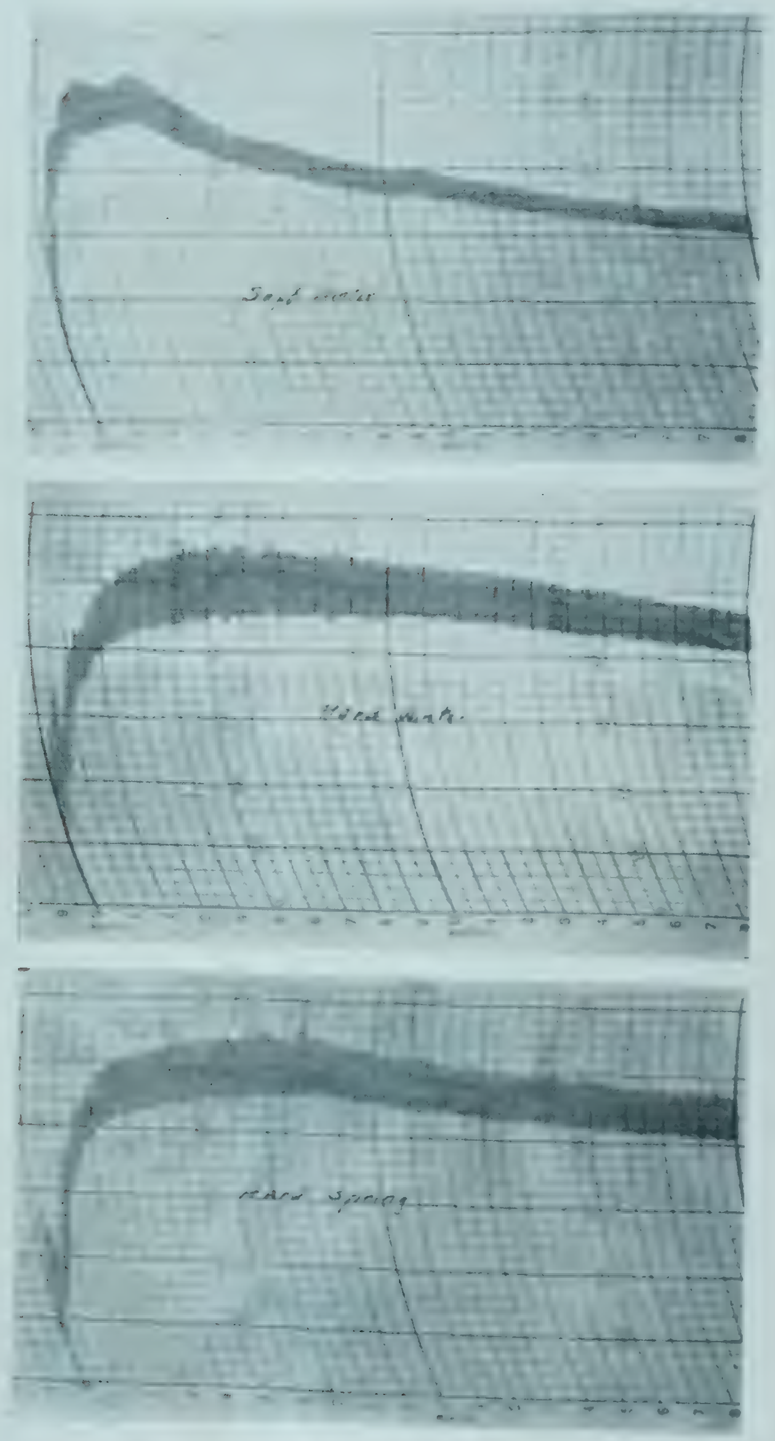


FIG. 7. COMPARATIVE FARINOGRAPH CURVES OF FLOURS FROM DIFFERENT TYPES OF WHEAT

(*a*) *Absorption.*—This is the percentage of water in the dough at consistency such that the farinograph curve centers on the 500 Brabender-Unit line at point of maximum development.

(*b*) *I—The time in minutes from start of mixing curve until top of farinogram* band touches the 500-unit line.

(*c*) *M—Mixing time* or development time. The time in minutes from start of mixing curve to peak of curve.

(*d*) *R—Mixing tolerance.* The time in minutes from *I* until the top of the curve drops below the 500-unit line.

(*e*) *D—Number of Brabender units* as indicated on curve from 500-unit line to center of farinogram band 20 minutes after starting the mixer.

(*f*) Drop of 30 Units— *Time from start of mixer until middle of curve* is 30 units below 500-unit line.

(*g*) *Consistency drop*—Brabender units from 500-unit line to middle of curve 15 minutes after peak (*M*).

(*h*) *M.T.I.—Mechanical tolerance index.* This is the drop in Brabender units from the peak (*M*) to a point 5 minutes after the peak, both points being measured at the top of the band.

(*i*) *Valorimeter Value—The valorimeter value,* which is an empirical figure based on dough development time and mixing tolerance, is read off the farinograph curve by a special template.

The farinograph curve is expected to give information on absorption, mixing time, and mixing tolerance. Care must be taken in interpreting farinograph data because of the variation from year to year of farinograph correlation with baking quality. Comparative data on samples of hard spring and hard winter bakers' patent and soft short patent flours are given in Table 15 and Fig. 7.

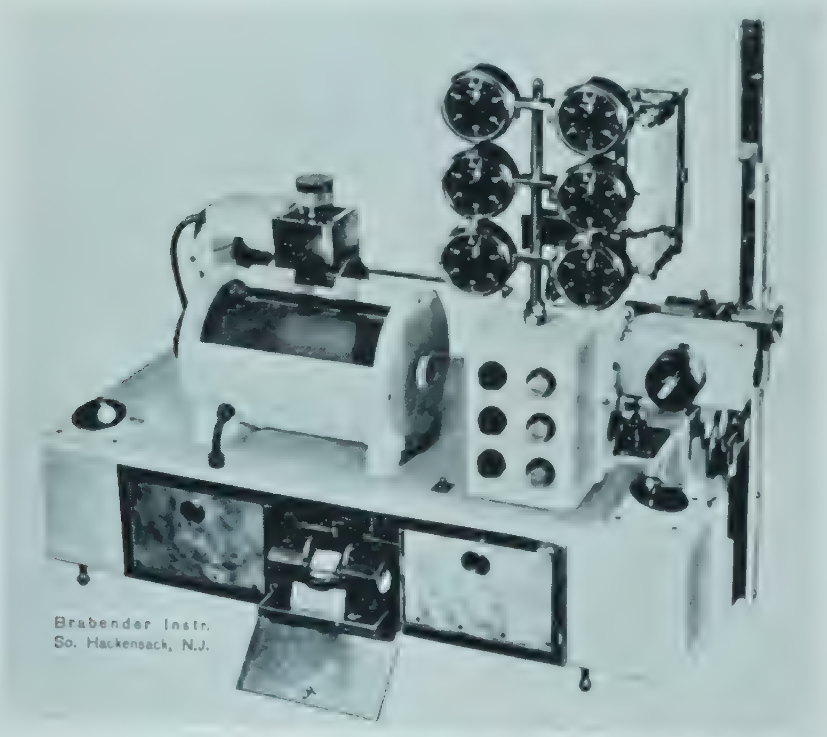
TABLE 15

COMPARATIVE ANALYTICAL AND FARINOGRAPH DATA ON SOFT, HARD WINTER, AND HARD SPRING PATENT FLOURS

	Spring Bakers Patent[1]	Winter Bakers Patent[1]	Soft Short Patent[1]
Ash, per cent	0.43	0.44	0.30
Protein, per cent	12.50	11.90	7.50
Absorption (farinograph), per cent	61.5	55.9	52.0
I (minutes)	2.5	2.5	1.0
M "	8.5	8.0	3.0
R "	11.0	12.5	3.0
D (Brabender units)	60.0	55.0	180.0
M.T.I. " "	40	20	115
Drop of 30 Units (min.)	13	15	4
Valorimeter	70	69	38

[1] The farinograph curves for these samples are shown in Fig. 7.

The **Brabender extensograph** (Fig. 8) is a device for measuring and recording the extensibility and resistance to extension of flour doughs. A definite quantity of dough at established consistency is placed in the cradle of the extensograph and then by a mechanized arm the amount of extension per unit of time is recorded. The height of the extensograph curve indicates the dough's resistance to extension and the length of the curve as measured on the horizontal axis, its extensibility.



Courtesy of C. W. Brabender Instruments Co.

FIG. 8. THE BRABENDER EXTENSOGRAPH

The extensograph curve is expected to show the degree of maturation of the flour used in the dough as well as its fermentation and machining behavior.

The **Brabender amylograph** is a recording viscosimeter which provides a continuous automatic record of the viscosity changes which occur in a flour-water suspension being subjected to a uniform increase in temperature. The viscosity of the sample of flour dough or suspension in water tends to increase as the starch gelatinizes while the alpha-amylase present tends to liquefy the gelatinized starch, thus providing a measurement of the extent of enzyme activity.

The manufacturer claims that this device provides information that can be used as a guide for proper addition of enzyme to flour to provide adequate sugar for fermentation, and for control of crumb softness and rate of staling.

Brown and Harrel (1944) describe the use of the amylograph in controlling enzyme activity in rye flour where excessive amylase activity will yield a soggy, wet crumb. Proper enzyme activity as indicated by the amylograph curve will give superior crumb and good quality finished products.

The **Mixograph** was developed by Swanson and Working (1933). It consists of a mixing bowl which is placed in the center of a lever and a pin type mixer for mixing the dough. Increased pull of the gluten as it develops is transmitted through the bowl onto a chart. Information relative to dough development, stability, absorption, etc., are read from the curve. However, Johnson *et al.* (1943) in a study of the relationships of mixograms to baking results concluded that the mixograms were of greatest value in supplying supplementary information with regard to mixing requirements, mixing tolerance, etc., which may or may not be related to the actual baking quality of the flour itself.

Other Physical Tests.—A large number of other physical tests are used to a lesser extent in the evaluation of flour. Among these are **sedimentation,** as developed by Zeleny (1947), the Chopin **Alveograph** which is a measure of extensibility or resistance to expansion of a thin dough, and many others. All of these physical tests have very obvious limitations in that they evaluate gluten quality in an empirical fashion under a rather limited range of conditions and consequently they do not evaluate baking quality of the sample under consideration. However, they no doubt do serve a useful function in indicating certain factors relative to flour or gluten quality, and changes in physical dough characteristics as measured by these various machines can be taken as an indication of differences in the properties of the flour from time to time. This may or may not be of significance to the baker. In the light of this, it is obvious that the physical tests, as such, must be supplemented with other types of tests, such as chemical evaluation, to indicate gluten quality as well as baking tests themselves which must be looked upon as the final criteria of flour and gluten quality.

Organoleptic and Performance Tests and Their Significance

Performance Tests.—The baking test is an attempt to simulate actual conditions under which the flour is to be used and thereby get an overall evaluation of its properties not attainable by any of the physical or chemical methods previously described. The baking test itself, however, is difficult to control because of the variability of the ingredients as well as the fact that it is based on a biological phenomenon, namely the growth and metabolic processes of the yeasts themselves which, in turn, are subject to all environmental factors.

Further, in commercial baking operations a wide variety of formulas and procedures are used which create widely different demands on the quality of the flour; hence, evaluating flour for vastly different processes and end products by one standard baking test is, at the best, only of limited value in judging baking quality. It is, therefore, necessary in the evaluation of flour by the baking method to test it under various modifications of the basic procedure in order to establish fully its quality.

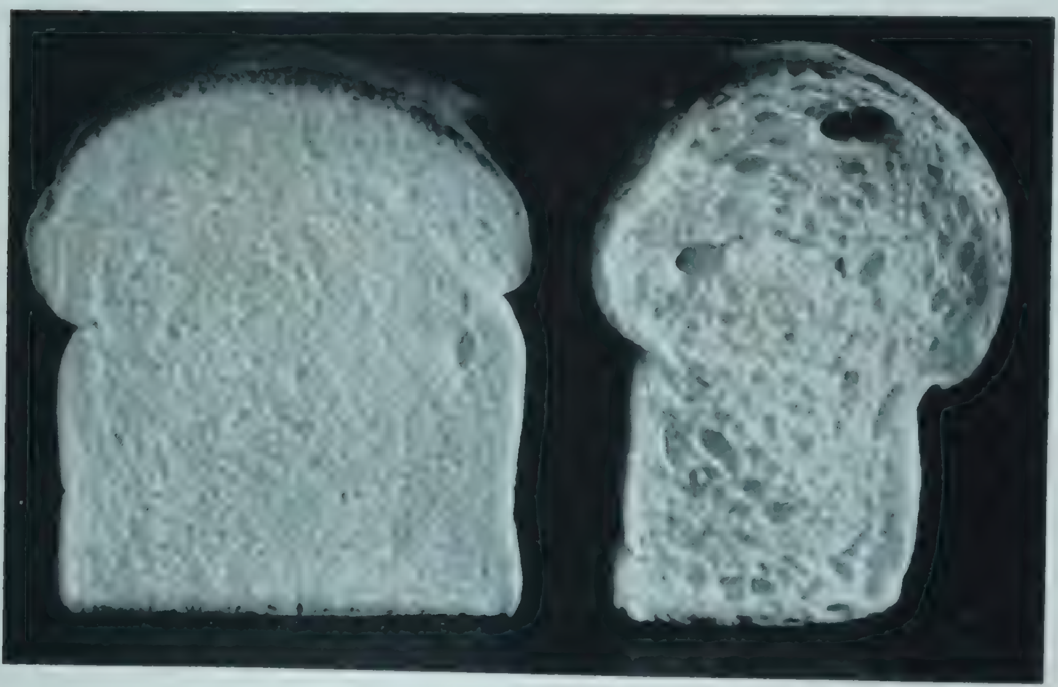


FIG. 9. CROSS SECTIONS OF PUP LOAF AND ONE-POUND LOAF

In spite of the shortcomings of the baking test, it still gives the best overall evaluation of the flour quality. Bread baking test methods can be divided up into two general categories—the sponge and dough method, and the straight dough method. The sponge and dough method is based on making a soft dough with from one-third to one-half or more of the flour and the yeast, fermenting for a time, and then adding the remainder of the flour and the other ingredients, mixing, and further fermenting. In the straight dough all constituents are mixed together before fermentation. While no baking method will furnish all the information desired in testing a sample of flour, the American Association of Cereal Chemists, through a committee of its members, has devised standard experimental baking methods for both straight dough and sponge and dough procedures (Anon. 1957).

The Straight Dough Procedure.—The straight dough procedure is a small scale or "pup" method requiring only 100 gm. of flour for a test, mixing by machine, and moulding either by hand or by machine. The method is valuable in giving a general indication of baking quality, particularly loaf volume; however, the limitation of the method and the size of the resulting loaf preclude accurate evaluation of the behavior of the dough itself or the internal properties of the loaf obtained. It does, however, furnish limited useful information in comparing various flours for general baking use.

The Sponge and Dough Procedure.—The sponge and dough method of the American Association of Cereal Chemists is run on a somewhat larger sample requiring 280 gm. of flour and producing approximately a one-pound loaf. Both mechanical mixing and moulding are used. The larger loaves obtained by this method make possible closer comparison and evaluation of grain, texture, color, etc. (Fig. 9) than is possible with the "pup" loaf.

Modifications of the standard American Association of Cereal Chemists' **Pup Method** include:

(*a*) ***Mixing response.***—In this procedure the doughs are mixed for varying lengths of time and the change in character of the resulting loaves noted. Evaluation of flour by this technique will give information on optimum mixing time and mixing tolerance under the conditions of the test.

(*b*) ***Fermentation response.***—By varying fermentation time and noting effect on the character of the resulting doughs, information can be obtained on optimum fermentation time and tolerance.

(*c*) ***Bromate response.***—In this test increments of potassium bromate are added to the doughs and the results are noted in terms of finished loaf. This test is particularly useful in evaluating flours to be used in the production of hard rolls where high bromate treatment is important in supplementing the mixing procedure.

While these various standardized test methods as developed by the American Association of Cereal Chemists are valuable in evaluation of flour, they have been subject to considerable criticism because of their lack of flexibility and are considered by Kent-Jones (1934) to have only very limited application in evaluating flour quality. He recommended that further consideration be given to the study of the properties of the dough which would yield themselves more readily to precise measurement. This seemed to be substantiated to a considerable degree in the collaborative study carried out with Geddes (Kent-Jones and Geddes 1936).

Organoleptic Tests.—Since the end use of most wheat flour is in food products, it is essential that it be free from foreign or undesirable odors and flavors. Flour will absorb the odor from such materials as oil, or tar, if exposed to them. Occasionally objectionable seeds such as garlic, wild onion, and melolot, cannot be completely removed from the grain by conventional cleaning equipment, and induce undesirable odors and flavors in the finished product. Testing for off-odors in flour is sometimes facilitated by mixing the sample in question with 2 or 3 volumes of hot water and cautiously sniffing the vapor while stirring vigorously. All organoleptic tests are somewhat unreliable in the hands of a layman, but to one thoroughly experienced with them and having trained senses of smell and taste, they can be highly accurate. Organoleptic tests are used in evaluating the bread obtained in the baking test and odor and taste evaluations are included in the overall score.

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CHAPTER 2

Henry J. Peppler

Yeast

The functions of yeast in breadmaking are to lighten the dough and impart to it a characteristic aroma and flavor. This was the role of yeast for thousands of years before its existence was recognized. This remains its destiny today, although its activities have been improved progressively through scientific modifications in the manufacture of bakers' yeast and a broader understanding of bread making processes.

The biochemical and biophysical transformations caused by bakers' yeast appear simple enough. Their practical achievement is complicated significantly by the natural qualitative and quantitative variations in raw materials, as well as by changes in their processing, and the subsequent influence of handling methods.

Four kinds of yeast are available to the baker. Living yeast for leavening is marketed as compressed yeast or as active dry yeast, containing about 30 per cent and 92 per cent solids, respectively. Dead dried yeast for nutritional and flavor enhancement is furnished as specially-processed bakers' yeast for white bread and as food yeast for rye bread.

BIOLOGICAL PROPERTIES OF BAKERS' YEAST

This vital element upon which the baker is so dependent is an oval-shaped, one-celled, colorless, microscopic plant called *Saccharomyces cerevisiae* (from Latin roots signifying "sugar fungus" and "grain with vigor," i.e., beer). Cells normally exist singly and occasionally in pairs, giving rise to new cells by budding. This reproductive power is repeated innumerable times. Barton (1950) observed the occurrence of 23 successive buds from one cell.

Resistant reproductive units named ascospores commonly develop in the natural environment; however, their occurrence in the laboratory must be forced by special culture conditions. They have never been observed in commercial yeast.

Yeasts vary markedly in size. Strains grown as bakers' yeast average from 4μ to 6μ in width (μ = micron = 0.001 mm.) and 5μ to 7μ in length. Greater variations in size are found in laboratory propagations due to the greater variety of nutritional and cultural conditions provided.

HENRY J. PEPPLER is Manager of Research, Red Star Yeast and Products Co.

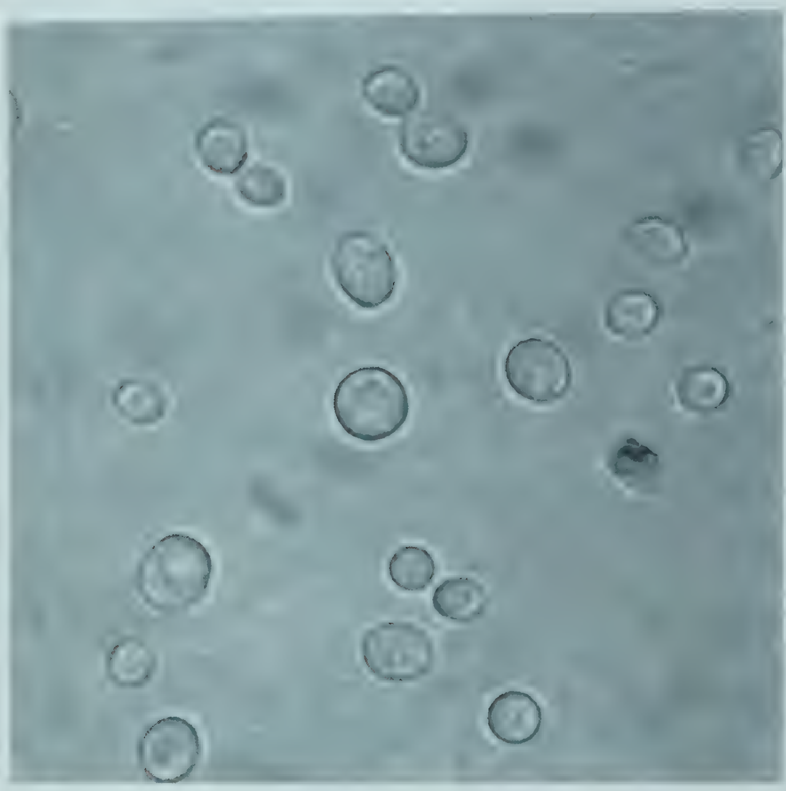


FIG. 10. MICROSCOPIC APPEARANCE OF LIVING COMMERCIAL BAKERS' YEAST, *Saccharomyces cerevisiae*

Different varieties or strains of S. *cerevisiae* are selected for cultivation and use in the baking and brewing industry. Photomicrographs of typical commercial bakers' yeasts are shown in Fig. 10. Other species of *Saccharomyces* are found better suited to wine and spirits production. Another type of yeast in large-scale production, a non-sporeforming type, *Candida* (*Torulopsis*) *utilis*, Fig. 11, is marketed chiefly as a dried, nonliving nutritional and flavor supplement for rye bread, other foods and feeds. A related species, *Candida monosa*, has found commercial application in the egg-desugaring industry because of its selectivity for hexose sugars.

According to Stodola (1958), about 500 species of yeast, 2,000 species of bacteria and 40,000 species of fungi are recognized by taxonomists, the scientists who strive to maintain a workable arrangement of organisms based on natural chemical and anatomical relationships. Such orderly classification of yeasts has been compiled by Lodder and Kreger-Van Rij (1952). In contrast the chemist has classified about 750,000 compounds, but only approximately 3,000 of these have become useful in industrial, agricultural and medical applications.

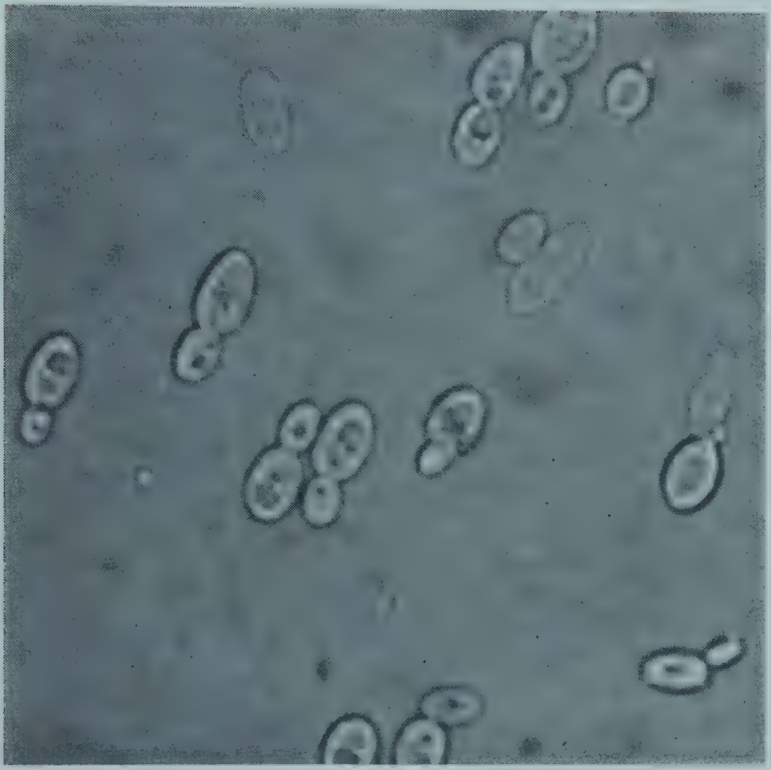


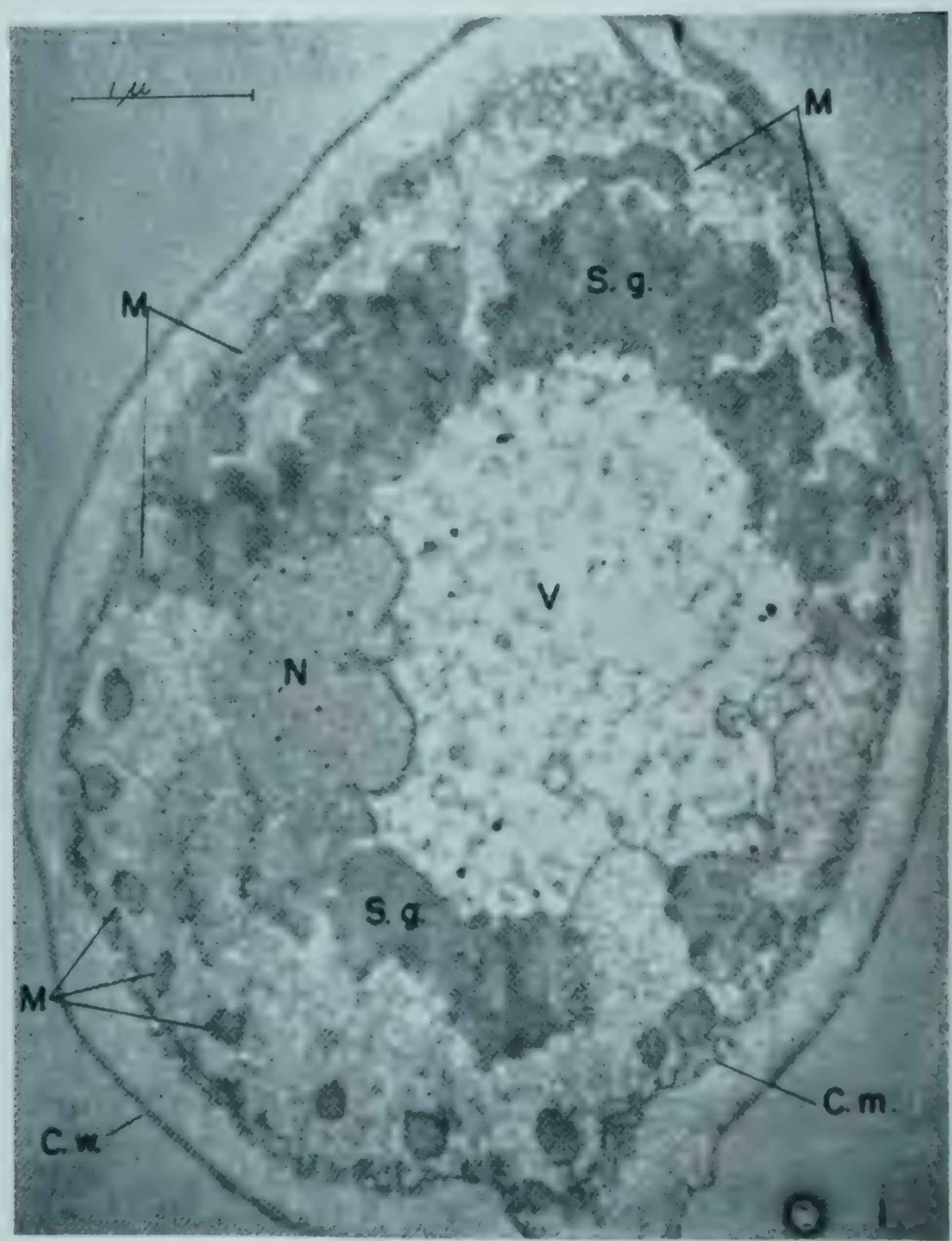
Fig. 11. Microscopic Appearance of a Culture of Food Yeast, *Candida (Torulopsis) utilis*

Habitat

Yeasts, like all micro-organisms, are universally distributed, generally growing harmlessly on various parts of plants wherever sugar is available. A few are found in the bowels of man, herbivorous animals and insects. However, as Lund (1954) has reported, the soil is the main repository of yeasts, providing protection during periods unfavorable to growth, and serving as a major avenue of dissemination via air-borne dust. Very few yeasts are causative agents in the diseases of man and plants.

Anatomy

Varieties of bakers' yeast cannot be distinguished from each other or from brewers' yeast by their shape, size, color, colony appearance or cellular structures. Microscopic study readily reveals the three main parts of the cell: the rigid cell wall, the dense nucleus, and the cytoplasm surrounding it. Within the cytoplasmic meshwork are discernable vacuoles, fat globules, glycogen, volutin, storage particles and other pieces of cellular machinery whose differentiation is enhanced by special dyes and staining procedures.



Courtesy of Prof. H. C. Douglas, University of Washington

FIG. 12. ELECTRON MICROGRAPH OF ULTRA-THIN SECTION OF *Saccharomyces cerevisiae*

Abbreviations refer to cell structures: C. m. = cytoplasmic membrane, C. w. = cell wall, M = mitochondrion, N = nucleus, S. g. = storage granule, and V = vacuole.

The development of the electron microscope has greatly broadened the study of microbial structural detail. An electron micrograph (Fig. 12) reproduced from Agar and Douglas (1957), reveals cellular components seen for the first time. Noteworthy are the cytoplasmic membrane directly beneath the cell wall and the elliptical profiles of particles identified as mitochondria arranged in the peripheral regions of the cytoplasm.

Specialized functions are known for each of the discrete cellular parts. As new tools and techniques are applied to these micro-structures, more direct evidence of their function is added to the meager knowledge of living chemistry. For example, the yeast cell wall, consisting largely of glucan and mannan and constituting 15 per cent of the cell dry weight (Northcote and Horne 1952), appears to have an outer metabolic region according to the studies of solute penetration reported by Conway and Downey (1950). A greater role in the cell surface by enzymes, the catalytic compounds regulating practically all physiological reactions, is predicted by Rothstein *et al.* (1959). Likewise the location of hexokinase at the surface is argued, while other enzymes of the cell surface may be concerned with extracellular digestion and active transfer of metabolites across the cellular membranes. Eddy (1958) found invertase activity in isolated cell wall fragments.

In the nucleus of yeast resides its hereditary and regulatory mechanisms. Due to its minute size (about 0.5μ to 1.5μ diameter), progress in unraveling its actual structure is slow. At present cytological interpretations of the yeast nucleus and chromosomes are so divergent that it is impossible to give a description which would be generally acceptable.

Genetics

The main facts of inheritance in yeast were established by Winge and Laustsen (1938) and enriched by Lindegren (1949) and others. Their basic observations, reviewed by Gilliland (1958), opened the way to the application of modern principles of yeast genetics and systematic hybrid production for improvement of yeast for baking and brewing. Success in these investigations has been limited to modification of a single criterion such as increased yeast yield or faster leavening action. The development of superior yeast hybrids depends upon the following premises:

(1) *Saccharomyces* cells exist in both the haploid and diploid state, i.e., one set and two sets of chromosomes, respectively; (2) vegetative cells are normally diploid, the result of conjugation of two haploid spores or mating-cells from spores; they form diploid buds which develop into exact replicas of the mother cell, and can be grown indefinitely by asexual budding; (3) sporulation can be induced, the spores are haploid

and can be maintained as haploid cultures, asexually, by budding for long periods; (4) single spores brought together conjugate sexually, forming a hybrid (diploid) yeast; and (5) haploid cells can be mated with each other to produce a hybrid (diploid) yeast.

Combined with Lindegren's (1956) classification of yeast properties under genetic control, Gilliland (1958) recognized fourteen characters, several of active interest to investigators in the bakers' yeast industry. These are arranged in Table 16. As yet there appears to be little commercial interest in the polyploid yeasts although they exceed diploids in size, fermentation rate and yield.

Table 16

SOME CHARACTERS OF SACCHAROMYCES UNDER GENETIC CONTROL

Cell Type	Resistance to	Content of	Ability to Make
Size	Sugar conc.	Respiratory enzymes	B-vitamins
Color	Salt conc.		Purines
Growth rate	Alcohol conc.		Pyrimidines
Flocculation	Cation conc.	Specific hydrolytic enzymes	Amino acids
	Autolysis		

The cytoplasm surrounding the nuclear apparatus is the main arena of chemical activity. Within this matrix of visible bodies, veiled inner membranes and submicroscopic particles, sugars are converted to release energy, new combinations of chemicals are made from inorganic and organic nutrients, and new cell parts are formed to reproduce the cell.

Fermentation is the principal energy-yielding mechanism and the dominant action fostered in bread doughs. For this the intact cell remains the most efficient and practical fermenter. Cell saps obtained by fracture of the cell wall and tested under ideal conditions ferment at less than half the rate of the whole cells.

BIOCHEMICAL PROPERTIES OF BAKERS' YEAST

Fermentation

Long before mankind knew of yeast its presence could be discerned by its visible and tasteful transformations of extracts of fruits and grains. Centuries spanned the first occurrence of flavor enhancement in a wheat porridge by natural infection (McCance and Widdowson 1955) to the ancient Egyptians who recognized leavening action and by 2600 B.C. practiced bread making by methods akin to those followed in modern times (Horder *et al.* 1954).

The phenomenon of fermentation remained in the realm of the occult even after van Leeuwenhoek in 1685 observed the structure of the yeast cell with his crude microscope because he failed to perceive its living role in the wine and beer he examined.

Chemists of that time favored the concept that fermentation was purely chemical alteration, basically as Gay-Lussac proposed in 1810: one molecule of sugar was transformed to two molecules each of carbon dioxide and ethyl alcohol. Since yeast appeared not to contribute measurably to the reaction, its importance was denied.

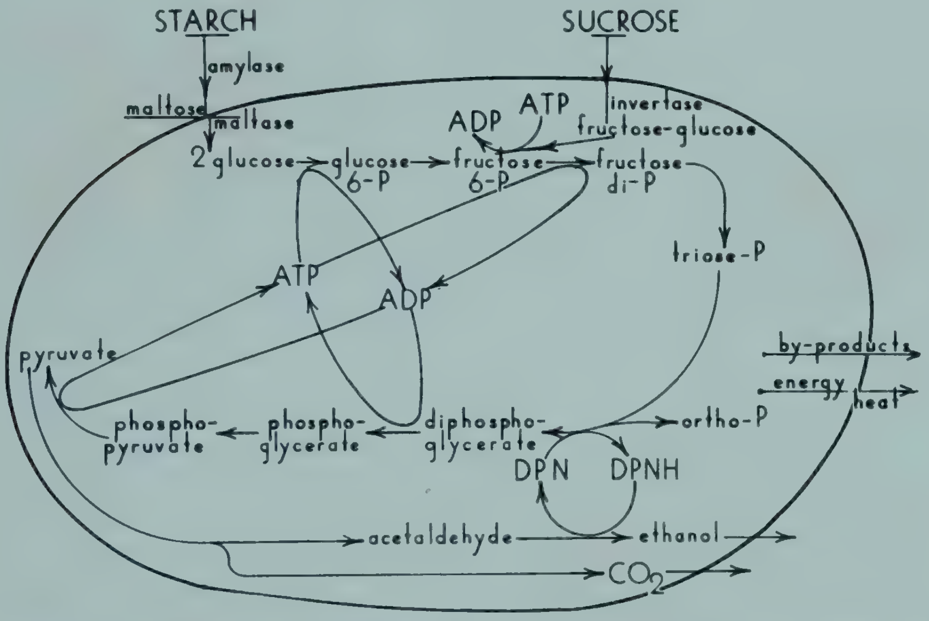

STARCH
SUCROSE
amylase
maltose
maltase
invertase
ATP
ADP
fructose-glucose
2 glucose
glucose 6-P
fructose 6-P
fructose di-P
triose-P
ATP
ADP
pyruvate
by-products
energy
heat
phospho-pyruvate
phospho-glycerate
diphospho-glycerate
ortho-P
DPN
DPNH
acetaldehyde
ethanol
CO2

Fig. 13. Schematic Representation of the Sequence of Carbohydrate Metabolism and Fermentation by Bakers' Yeast

In the midst of mounting reports that yeast was a living microbe and was vital to the occurrence of fermentation, Meyen in 1837 named it the "sugar fungus" or *Saccharomyces*.

The scientific controversy reached a climax in 1857 with the studies of Pasteur. His keen observations and genius for perception provided proof for the vitalistic theory of fermentation, that "The breakdown of sugar into alcohol and carbonic acid is a correlative action of a vital phenomenon, an organization of cells, in which organization the sugar takes a direct part by supplying a portion of the constituents of the substance of those cells" (Vallery-Radot 1957). His observations further established concepts which have withstood a century of examination:

(1) yeast exists and is active in air as well as in the absence of air, and its behavior changes accordingly; (2) in the presence of air yeast growth

is rapid and little alcohol accumulates (aerobiosis); (3) without air yeast growth is slow but alcohol formation is increased (anaerobiosis); and (4) besides alcohol and carbon dioxide other compounds, such as glycerol and succinic acid, occur normally in yeast fermentation.

Toward the end of the 19th century, Fischer extracted the enzymes invertase and maltase from yeast and established their specific catalytic function in the hydrolysis of the sugars sucrose and maltose. The achievements of Buchner quickly followed in 1897, demonstrating that an extractable enzyme complex, zymase, was capable of converting sugar to alcohol and carbon dioxide in the absence of the intact yeast cell. In the decades to follow, the intensive research on the sequence of biochemical changes has brought forth many details of the complex reaction mechanisms. The principal steps are embodied in the stylized diagram, shown in Fig. 13, illustrating three of the four phases of carbohydrate metabolism in yeast: *first*, the hydrolytic preparation of carbohydrates to permit passage of sugar through the membranes into the cell (Conway 1958); *second*, modification of sugar through mediation of adenosine triphosphate (ATP) to initiate the energy-yielding reactions; *third*, decomposition of the sugar phosphates and their intermediates anaerobically to carbon dioxide, ethyl alcohol and additional ATP; and *fourth*, formation of cell constituents, synthesized with help from ATP.

Thus ATP serves as a link between the metabolic reactions releasing energy and the cell-building processes requiring energy. The series of internal oxidations and reductions within the cell, phases two and three above, are known as the Embden-Myerhof-Parnas (EMP) pathway of glycolysis (fermentation), and the reactions of each pair of intermediates is catalyzed by specific enzymes and co-factors freely suspended in the yeast cell. By this anaerobic pathway the carbon dioxide emanates from sugar carbon atoms 3 and 4.

Other systems for metabolizing carbohydrates exist in yeast. The main aerobic system, the Krebs or tricarboxylic acid (TCA) pathway, which oxidizes pyruvate to water and carbon dioxide occurs in the specific intracellular structures called mitochondria. Carbon dioxide from this system is derived equally from all six carbon atoms of the hexose sugar acted upon. Of minor importance here is the oxidative shunt operating from glucose-6-phosphate (hexose monophosphate shunt or HMP), wherein carbon dioxide is preferentially liberated from sugar carbon-1. As will be noted later, aerobic pathways yield the most energy.

Microclimate

The biochemical problems of yeast fermentation, the basis of leavening, are modified and multiplied upon the distribution of yeast in bread dough. There the action of this 0.5 per cent of vital solids in the dough is subjected to the influence of a vast number of ever-changing physical, chemical and biological factors—the microclimate in which bakers' yeast is compelled to work.

To work at its best, yeast requires (1) a balanced nutritional diet of sugar, available nitrogen, minerals, vitamins and water, and (2) an optimum environment with respect to such rate regulators as temperature, enzymes, oxygen, acidity, nutrient concentration and time.

Nutrients

As Pasteur led the way to the fundamentals of fermentation chemistry, Hansen (1896), a physiologist, pioneered the development of methods for separating mixtures of yeast into single, pure cultures, thereby to study scientifically the factors affecting yeast action. His pure culture techniques, including even the isolation of a single yeast cell and its nourishment to visible growth, established the importance of yeast strain selection for industrial processes. This dependence of yeast behavior on its hereditary and evironmental factors still occupies a prominent place today in bakers' yeast research programs.

In light of modern studies with culture media of known chemical composition, the nutritional factors essential for yeast growth can be defined. The basic needs of bakers' yeast are illustrated by reference to the synthetic medium devised by Olson and Johnson (1949) which produced greater yeast crops than those reported for molasses and other natural substrates. Their strain of bakers' yeast attained a yield of 53 gm. dry yeast/100 gm. glucose in an aerated solution of glucose, serine, phosphate salts of potassium and ammonium, magnesium sulfate, traces of zinc, iron and copper, and vitamins—biotin, thiamin, pyridoxine, inositol, and calcium pantothenate.

Serine could be replaced by other amino acids, asparagine and alanine, without appreciable change in productivity. In studies with other strains of bakers' yeast, Chen (1959A) showed yields of nearly 50 per cent in a similar medium devoid of amino acids.

In addition to glucose, which is preferentially utilized by most biological mechanisms, bakers' yeast ferments the hexoses fructose and mannose, the dihexoses sucrose, maltose and trehalose, the trisaccharides raffinose and gentianose (one-third fermented), and the tetrasaccharide stachyose (one-fourth fermented). Lactose (milk sugar) is not attacked by bakers' yeast. Strain differences in yeast will affect the rate and extent of sugar dissimilation as well as the metabolism of other carbon compounds, such as alcohols, organic acids, aldehydes and amino acids. Yeast versatility in the transformation of carbon compounds is reflected in the compilation by Wallen *et al.* (1959), who listed 233 different fermentation reactions performed by yeast. Of the 14 type reactions considered, yeast performed eight, reduction exceeding in frequency all others (Table 17).

Table 17

TYPE REACTIONS PERFORMED BY YEAST

Reaction	Number	Reaction	Number
Reduction	156	Esterification	10
Decarboxylation	21	Condensation	9
Deamination	17	Hydrolysis	5
Oxidation	14	Amination	1

Sucrose and its components, glucose and fructose, which together constitute invert sugar, are fermented with great ease by bakers' yeast; some strains exhibit a slightly faster fermentation rate on glucose. Under ideal conditions at 86 F. this rate approximates one gram glucose hour gm. yeast at 30 per cent solids (Nickerson and Schultz 1957).

The free sugar content of flour is about one per cent (MacKenzie 1958), and the rate at which it becomes fermentable is dependent upon the strain of yeast employed.

Nitrogen is required in abundance to build protein and nucleic acids, which together comprise more than half of the yeast dry matter. Inorganic ammonium salts, urea and amino acids are metabolized readily. A few other nitrogenous compounds, allantoin, guanine, adenine and cytosine are available in varying degree to bakers' yeast (Di Carlo *et al.* 1951).

Nitrogenous compounds are plentiful in dough, but the addition of ammonium chloride, a component of yeast foods, generally stimulates fermentation.

Eight mineral elements are essential for yeast growth; some are integral constituents of enzymes and function as cofactors in fermentation. Those needed in relative abundance are magnesium, phosphorus, potassium, sodium and sulfur, readily supplied as phosphate and sulfate salts. Only trace amounts of copper, iron and zinc are essential to yeast propagation and fermentation.

The natural ingredients of bread dough are believed to contain adequate levels of minerals for yeast action (Atkin *et al.* 1945). Bread doughs made up with soft water show faster proof times upon the addition of calcium sulfate (gypsum), also an ingredient of many yeast foods (Helbert and Thorn 1958).

Traces of some vitamins added to media otherwise adequate in sugar, nitrogen and salts are required factors for cell growth, while others merely stimulate gas production. In this regard bakers' yeast strains vary widely.

The following are beneficial for maximum growth, but do not appear to modify fermentation rates of bakers' yeast if adequate levels were available during yeast propagation: biotin, pyridoxine, thiamin, pantothenic acid, inositol and niacin.

Vitamin deficiency is not a normal occurrence in bread making (Atkin *et al.* 1945); and there is no evidence that fortification of doughs with thiamin or pyridoxine affects the leavening action of yeast.

Rate Regulators

In addition to an adequate supply of nutrients and accessory compounds, the optimum performance of yeast is dependent upon the influence exerted by several factors classed as rate regulators. These are water, enzymes, oxygen, temperature, hydrogen ion concentration (pH), nutrient concentration and toxic substances.

Water is the most abundant compound on earth and in living cells. It is indispensable to all biological systems, performing the manifold tasks of (1) providing an abode or medium in which micro-organisms are dispersed and suspended, (2) solubilizing constituents within the cell and nutrients outside the cell, (3) transporting metabolites into the cell and removing products of metabolism, and (4) participating in many reactions ranging from hydration and hydrolysis of polysaccharides, proteinaceous and lipoidal compounds to oxidations and reductions leading to their polymerization and synthesis.

In bread dough yeast encounters less water than is found normally in yeast cells—70 per cent. Then, as part of the dough make-up water hydrates ingredients, even less free water is available to the yeast—and a portion of that is bound up during hydrolysis, as for example, in the inversion of sucrose, resulting in a gain of 5.26 per cent in fermentable sugar.

(lbs.) 100 sucrose + 5.26 water =
52.63 glucose (dextrose) + 52.63 fructose (levulose)

Protoplasmic regulation of the water supply in the cell is a complex problem of adjustment for bakers' yeast in view of the concentrated solution of sugar, salt and minerals in which it is bathed.

Enzymes and co-enzymes are nitrogenous compounds formed by living cells from vitamins and numerous other building blocks for the purpose of accelerating the cellular reactions of digestion, fermentation, synthesis and transport of metabolites. In these catalytic functions enzymes are not consumed; however, their performance is influenced markedly by temperature, pH, concentration of reactants, etc. Based on a true yeast protein content of 40 per cent, at least one-fourth of it is enzyme protein (Johnson 1950).

Each enzyme has a specific function, causing only one type of reaction. This is an inherited quality. Consequently bakers' yeast, which probably has more enzymes than most micro-organisms, cannot digest starch or lactose because the respective hydrolytic enzymes, amylase and lactase, are not synthesized.

All evidence points to the intercellular location of enzymes, their release to the surrounding medium occurring upon death of the cell (Eddy 1958). The hydrolytic enzymes of bakers' yeast are thus not secreted. As Demis *et al.* (1954) have shown, invertase is located on the surface of bakers' yeast, and under normal conditions it splits sucrose at a rate 300 times as rapid as the rate of glucose fermentation. Bakers' yeast is a preferred industrial source of invertase (Peppler and Thorn 1960).

When yeast is placed in a dilute sugar solution and adequately aerated, the sugar is utilized exclusively by the aerobic or oxidative pathway. In the absence of oxygen, or with greater sugar concentrations, the fermentative pathway manifests itself, releasing only eight per cent of the energy obtained by oxidation. The energy remaining in the alcohol can be obtained only by oxidation.

$$\text{Oxidation: } C_6H_{12}O_6 \rightarrow 6\ CO_2 + 6\ H_2O;\ -\Delta F = 686 \text{ kcal.}$$

$$\text{Fermentation: } C_6H_{12}O_6 \rightarrow 2\ CO_2 + 2\ C_2H_5OH;\ -\Delta F = 54 \text{ kcal.}$$

The effects of both pathways on yeast behavior are illustrated in Tables 18 and 19. These data, adapted from Chen (1959A), emphasize the need for highly aerobic conditions to produce the maximum yeast mass, and that the oxidative and fermentative systems share almost equally in providing the biological energy to form new cell matter. Such changes in growth conditions also produce variations in yeast composition. Thus Chen (1959B) has found trehalose to vary from two per cent of the total carbohydrate content in fermenting cells to 38 per cent in aerobically grown yeast.

In its leavening action in dough, yeast fermentation predominates, and 60 per cent of the free energy of fermentation (54 kcal.) is dissipated as heat (Thorne 1957).

The ability to consume oxygen may be lost. Although this is the most common hereditary defect of yeast, only about one per cent of a culture of yeast is incapable of aerobic growth (Lindegren 1958). Naturally this is of watchful concern to the propagator of bakers' yeast, but is without significance in dough leavening.

The most favorable temperature for bakers' yeast growth and fermentation is in the range of 84° to 90° F., depending upon the strain used. For other yeasts the optimum may lie between 77° and 95° F. At lower

TABLE 18

EFFECT OF AERATION RATE ON GROWTH EFFICIENCY

Aeration Rate[1]	Growth Efficiency[2]
69	49
20	35
17	28
7	15

[1] As mM oxygen per liter per hour.
[2] As grams dry yeast made from 100 gm. glucose.

TABLE 19

EFFECT OF AERATION RATE ON QUANTITY OF CARBON DIOXIDE FROM DIFFERENT PATHWAYS OF GLUCOSE DISSIMILATION

Aeration Rate[1]	Growth Efficiency[2]	Metabolic CO_2, Per cent		
		HMP[3]	TCA[3]	EMP[3]
69	49	6.1	42.6	51.3
15	31	4.4	15.1	80.3
7	13	4.3	0.7	95.0

[1] As mM O/l./hr.
[2] As grams dry yeast made from 100 gm. glucose
[3] HMP—hexose monophosphate shunt. TCA—tricarboxylic acid oxidative pathway. EMP-Embden-Myerhof-Parnas glycolysis.

temperatures growth and fermentation will proceed, but at much slower rates. Temperatures above 95°F. progressively decrease yeast activity with concomitant loss of viability; at 130°F. most cells are killed within five minutes. The data of Matz (1957), Table 20, indicates the degree of change in gas production in the range of 64° to 116°F.

TABLE 20

RELATIVE GAS PRODUCTION AT DIFFERENT TEMPERATURES[1]

Temperature, °F.	Relative CO_2 Evolved[2]
64	59
87.5	100
102	89
111	82
116	78

[1] Adapted from Matz (1957).
[2] After 90 min.

TABLE 21

EFFECT OF SUGAR CONCENTRATION ON GAS PRODUCTION[1]

Sucrose[2]	Relative CO_2 Evolved Strain C	Strain D
4	100	100
10	92	96
15	76	87
20	61	75

[1] From Thorn (1959).
[2] Per cent based on flour; modified dough system tested in Sandstedt-Blish pressuremeter.

Dough temperatures occurring during commercial fermentation range from 72° to 82° in cold weather and 78° to 88° F. in warm weather (Swortfiguer 1950, Rumsey 1959).

Yeast ferments and grows best in an acidic environment, tolerating acidities as low as pH 2 and showing a remarkable capacity to adjust the pH to its preferred pH near 4.5. In commercial practice doughs after mixing are near pH 6.0, approach pH 4.5 after fermentation and rise to approximately pH 5.2 after baking.

Interference with fermentation rates may develop due to high concentrations of nutrients and to the presence of toxic substances. High levels of sugar, as are commonly used in sweet doughs, affect the ability of bakers' yeast to ferment rapidly (Table 21). This type of inhibition is due to high osmotic pressure; and according to Thorn (1959), glucose, galactose, and sodium chloride added to a dough system to provide the same osmotic tension, inhibited gas formation equally.

Poisons of organic and inorganic nature influence yeast activity, reducing yeast productivity and quality and infrequently interfering with fermentation in bread making. Certain metals are to be avoided in the selection of equipment, while errors in sanitation may contribute unwanted residual germicidal agents. White and Munns (1953) reported the effect of different metals and compounds on yeast growth (Table 22), showing that an increased complexity of the composition of the growth medium provided some protection against poisons, probably due to the presence of chelating agents.

TABLE 22

POISONS PREVENTING YEAST GROWTH[1]

Substance	Sucrose Agar[2]	Molasses Agar[2]
Decyl dimethyl ammonium bromide	22	17
Cetyl trimethyl ammonium bromide	25	17
Mercury	40	50
Chlorine	125	200
Formaldehyde	225	225
Cadmium	350	500
Copper	400	> 500
Sulfur dioxide	1500	1250
Phenol	2500	2500

[1] Adapted from White and Munns (1953).

[2] Values are approximate p.p.m. of compound required to arrest growth completely.

Finney *et al.* (1949) found as little as one p.p.m. cadmium chloride produced a significant reduction in yeast activity and loaf volume. The problem originated with the poor results obtained with a new mixer, later found to have cadmium-coated planetaries.

ROLE OF YEAST IN BREAD MAKING

Combining a wide choice of basic ingredients with numerous methods of dough preparation and handling, the baker practices bread making with commendable success. The kind and quality of flour, the choice of active dry yeast or compressed yeast, and the type of formula selected, whether straight, sponge and dough, lean or rich, necessitates changes in mixing schedules and fermentation procedure. Likewise varying the yeast content, among other ingredients, affects the time of mixing, dough development and pan proof.

Regardless of the bread-making method employed, yeast action in panary fermentation leads primarily to two results:

(1) The formation and migration of carbon dioxide culminating in a network of cellular compartments, occupying about 120 cubic inches per pound of loaf, to lighten or raise the dough, thereby improving greatly its ultimate palatability; and (2) the simultaneous production and concentration of alcohols, aldehydes, ketones and acids contributing to bread aroma and flavor.

In its secondary role yeast alters the physical properties of dough, especially gluten elasticity, through the powerful stretching actions generated by the diffusion and accumulation of carbon dioxide throughout the dough mass. This rupturing of gluten cross-linkages is described variously by bakers and cereal chemists as mellowness, ripeness, maturity and dough conditioning. Or as Pyke (1959) expressed it allegorically, ". . . yeast must serve as the last domestic animal used for power . . . the horse, the mule, the ox for ploughing . . . —all these have been mechanized. Only *Saccharomyces cerevisiae* retains its place to pull on the gluten fibres of the dough to produce a desirable structure . . . ."

Perhaps this, too, shall pass—for even now some continuous dough-making systems have relegated yeast exclusively to its primary functions:

TABLE 23

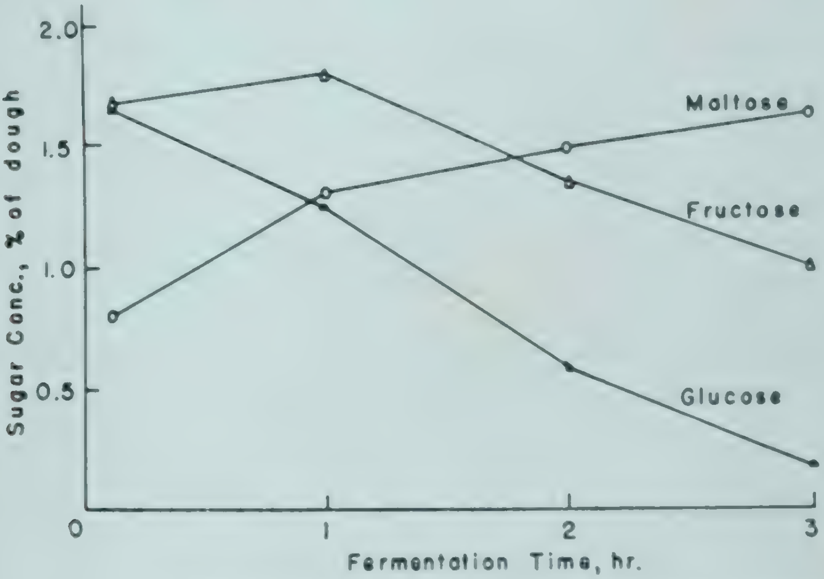
EFFECT OF YEAST CONCENTRATION ON PROOF AND VOLUME

CY[1]	ADY[1]	Proof[2]	Volume[2]
1.75	...	105	97
...	0.7	115	99
2.00	...	100	100
...	0.8	103	99
2.25	...	97	100
...	0.9	100	100
2.50	...	94	100
...	1.0	93	99
2.75	...	87	102
...	1.1	90	99

[1] Per cent, flour basis; CY = compressed yeast. ADY = active dry yeast.
[2] Average of eight loaves, relative values.

flavor enhancement and pan proofing. Others have demonstrated that dough mixed mechanically, leavened chemically, and flavored with yeast derivatives, produces a loaf indistinguishable from yeast leavened white bread (Chen and Peppler 1954, Matz *et al.* 1958).

Yeast usage has increased with changes in flour technology and bread-making techniques favoring savings in time and other economies of production. Twenty years ago most sponge formulas specified less than two pounds of compressed yeast per hundredweight of flour. Higher extractions of flour, and improved methods of maturing it, raised yeast levels to two and one-half per cent (Long and Brensike 1958). Some modified sponge and dough formulations are almost double that. The Navy Department's Bayonne bread formula specifies 1.8 per cent active dry yeast, equivalent to approximately four per cent compressed yeast, thereby reducing production time more than 50 per cent (Anon. 1959, Chussler and Gorman 1959).



Courtesy of R. B. Koch, QM. Food and Container Institute

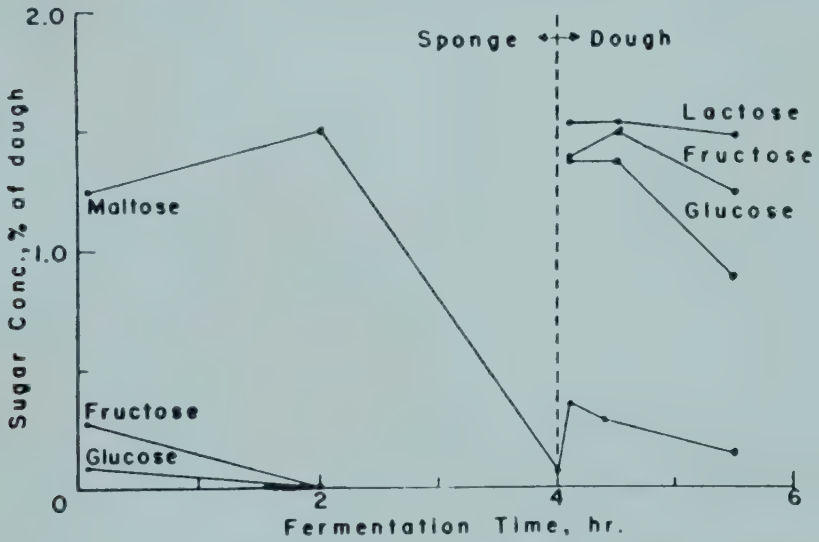
FIG. 14. CHANGES IN SUGAR CONTENT OF A STRAIGHT DOUGH FERMENTED AT 86°F.

For the brew-dough process the compressed yeast content is commonly at three per cent, and reaches ten per cent in some frozen doughs.

Concurrent with these technological changes has been the improvement of bakers' yeast quality—better color and physical properties, greater uniformity and stability, improved shelf-life and microbial purity, and increased gassing rates, some gains exceeding 20 per cent during the last decade.

The sponge and dough procedure remains the major bread-making method in commercial practice today (Rumsey 1959). Unless otherwise stated it is the system of reference in the ensuing review.

Active dry yeast (ADY) and compressed yeast (CY) perform leavening functions with essentially equal vigor in the average sponge and dough formula. ADY conversion rates commonly employed range from 40 to 50 per cent of the CY weight, or ratios of 1:2.5 to 1:2.0, ADY:CY, respectively. The lower conversion rates, meaning the lesser amounts of ADY, are favored as formulas increase in sugar content and are supplemented with amylase and yeast food, and high temperatures are used for sponges, doughs and proofing. An excellent review of ADY characteristics and usage has been compiled by Thorn and Reed (1959).



Courtesy of R. B. Koch, QM. Food and Container Institute

Fig. 15. Changes in Sugar Concentration of a Sponge and Dough During Fermentation at 86°F.

Yeast Content

The relative effects of yeast concentration, both ADY and CY, as compared in an average commercial sponge and dough formula by Merritt (1950), are summarized in Table 23. Increasing the content of either yeast shortened the proof time, but resulted in little change of loaf volume.

Effect of Ingredients on Yeast Activity

Sugars.—Yeast derives fermentable sugar from four sources: the cell, the flour, the hydrolysis of starch, and the sugars added intentionally. Cellular sugar, trehalose, triggers the fermentation mechanism of yeast

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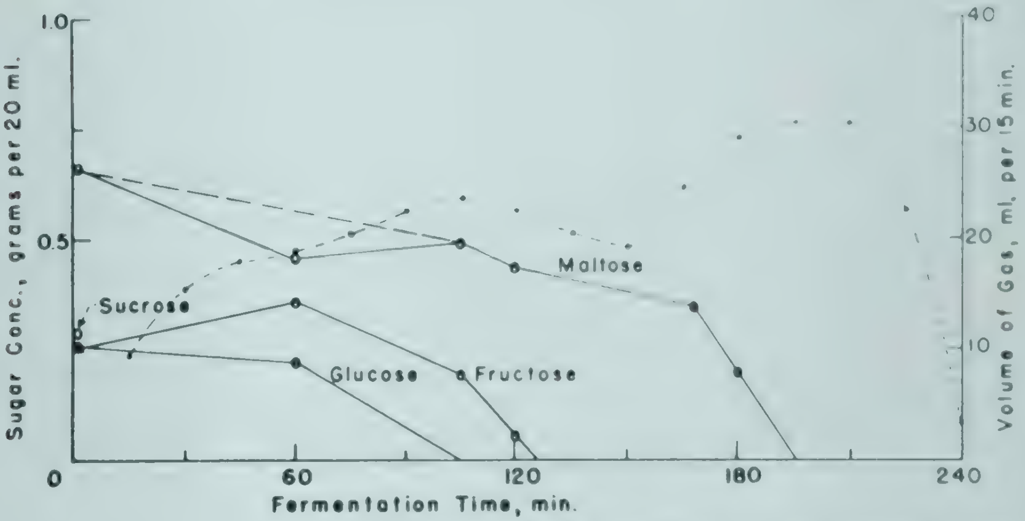
dispersed in a warm dough; and the action continues almost immediately on the free hexose sugars contributed by the flour and sugar supplements. In the late dough and proof stages, some of the maltose derived from hydrolysis of starch is fermented. Koch *et al.* (1954) determined the sequence and degree of sugar changes in straight doughs, sponge-doughs and synthetic media. In a straight dough made with three per cent CY and five per cent sucrose, Fig. 14, glucose was fermented in preference to fructose, while the maltose content rose even though an ample supply of hexose sugars was present to maintain yeast activity.



Courtesy of R. B. Koch, QM. Food and Container Institute

FIG. 16. RATE OF GAS PRODUCTION AND CHANGES IN MALTOSE AND SUCROSE IN A SYNTHETIC MEDIUM AT 86°F.

Broken line shows gas rate.

Similar analysis of a fermenting sponge and dough, with the sucrose addition at the dough stage, Fig. 15, demonstrated the adaptation of yeast to maltose fermentation, resulting in its increased utilization in both the sponge and dough stages. Here, too, glucose was fermented more rapidly than fructose, but the lactose, introduced with the non-fat milk solids, cannot be fermented by yeast and its content remained unchanged.

The same over-all changes observed in bread doughs were found when gas production rates and sugar concentration changes were determined in a nutrient synthetic medium containing equal amounts of sucrose and maltose. As Fig. 16 shows, maltose fermentation began slowly but increased sharply when invert sugar was exhausted, producing a marked burst in the gassing rate.

Not all the sugar in doughs is transformed by yeast. Koch *et al.* (1954) found the same maltose residual in bread whether by their sponge and dough method or by their straight dough procedure without added sugar; but twice as much maltose remained in the bread when sucrose, glucose or fructose was included in the straight dough formula. Bohn (1954) compared the sugar used during fermentation in various bread-making processes. Although wide differences can be expected because bake-shop conditions vary, the following comparison by Bohn is typical of sugar consumption during fermentation:

Type	Sucrose Added[1]	Used in Fermentation
Laboratory sponge dough	3	1.9
	6	2.2
	8	2.3
Commercial sponge dough	3	1.4
	7	2.7
Laboratory straight dough	5	3.2

[1] Values are per cent, flour basis.

In an average commercial sponge and dough system with CY, Table 24, sugar concentrations above two per cent increased proof time (Merritt 1950). Loaf volume, however, was optimum at four per cent sugar, and was accompanied by improved crust color, and internal characteristics up to six per cent sugar. ADY in the same dough system proofed equally as well at four per cent as at two per cent sugar, and performed better than CY at higher sugar concentrations. Prince (1958) noted that in sweet goods production the higher the sugar content, the better the relative performance of ADY vs. CY.

TABLE 24

EFFECT OF SUGAR CONCENTRATION ON PROOF AND VOLUME

	Proof[2]		Volume[2]	
Sugar[1]	CY	ADY	CY	ADY
0	256	218	89	94
2	100	100	100	100
4	107	100	101	100
6	108	103	101	100
8	115	108	98	99
10	129	. . .	98	. . .

[1] Per cent, flour basis.
[2] Average of eight loaves, relative values.

In a sweet dough system containing 20 per cent sugar, Thorn (1959) observed a conversion rate of 25 to 30 per cent—1.5 to 1.8 per cent ADY equalling proof times and loaf volumes produced by six per cent CY.

Yeast Food.—Yeast food supplements generally benefit the proof and loaf volume over a broad range, Table 25. At the higher yeast food levels,

Table 25

EFFECT OF YEAST FOOD LEVEL ON PROOF AND VOLUME

Yeast Food[1]	Proof[2]		Volume[2]	
	CY	ADY	CY	ADY
0	111	118	97	92
0.25	100	106	100	100
0.375	95	105	104	100
0.5	95	100	106	100
0.75	94	...	106	...
1.0	92	...	105	...

[1] Per cent, flour basis, bromate type.
[2] Average of eight loaves, relative values.

Table 26

INFLUENCE OF YEAST FOOD COMPONENTS ON PROOF TIME OF ADY

Component[1]			Proof, min.	
Gypsum	NH_4Cl	NaCl	Hard water	Soft water
0	0	0	61	64
0.13	0	0	61	62
0	0.05	0	55	57
0.13	0.05	0	54	55
0	0	0.13	65	62
0.13	0	0.13	65	61
0	0.05	0.13	56	57
0.13	0.05	0.13	54	54

[1] Per cent, flour basis; potassium bromate common to all combinations at 0.3 per cent of yeast food, used at 0.5 per cent, flour basis.

Table 27

EFFECT OF SALT CONTENT ON PROOF AND VOLUME

NaCl[1]	Proof[2]		Volume[2]	
	CY	ADY	CY	ADY
0	100	100	100	100
1.0	106	106	102	104
1.5	116	112	106	104
2.0	120	120	103	106
2.5	133	126	102	102

[1] Per cent, flour basis.
[2] Average of eight loaves, relative values.

the increased oxidant level improves sponge appearance, and loaf grain and texture, especially with ADY doughs. Besides the bromate, the active components in yeast food are ammonium chloride and gypsum, the latter being effective in shortening proof time in doughs made with soft water (**Table 26**).

Salt.—All levels of salt suppress yeast activity markedly (Table 27) increasing proof time 10 to 20 per cent in the optimal range (1.5 to 2 per cent salt) generally employed to toughen the dough, improve bread flavor and achieve maximum loaf volume. In the opinion of White (1954) the astringent action of salt on doughs prevents excessive stickiness and softening and suppresses bacteria to some degree.

Shortening.—In the absence of shortening, Merritt (1950) observed the lowest proof time, but it increased one minute with each one per cent increase in shortening up to five per cent. Beyond one per cent shortening, loaf volume was affected only slightly. Essentially the same behavior was observed with ADY and CY.

Non-fat Milk Solids.—Proof time remains unchanged from nil to six per cent non-fat dry milk solids in the representative sponge tested by Merritt (1950). With higher amounts of milk solids, proof time increased eight per cent. Loaf volume in the absence of milk solids was six per cent below the values found when 2 to 6 per cent milk solids were used. Incorporation of one per cent lactase, milk solids basis, to convert milk sugar for yeast fermentation in a sponge has no effect on proof time or loaf volume (Helbert and Thorn 1958).

Malt Sirup.—Zero to one per cent of a low diastatic sirup (20° L.) used in the dough end of a standard sponge and dough formula had no effect on proof time (Merritt 1950); and loaf volume was changed very little, although it was highest at one-half of one per cent malt.

Propionate.—Mold inhibitors also slow down yeast action. The marked lengthening of proof time, Table 28, was similar for both CY and ADY; but the latter was affected less at excessive propionate levels of one-half per cent. Bread standards permit 0.32 per cent. Neither test resulted in significant volume changes (Merritt 1959).

TABLE 28

EFFECT OF MOLD INHIBITORS ON PROOF

Yeast	Propionate[1]	Proof[2]
CY	0	100
	0.25	119
	0.50	161
ADY	0	105
	0.25	120
	0.50	124

[1] Per cent, sodium salt.
[2] Relative values.

Non-nutritive Sweeteners.—Evaluation of calcium cyclamate in straight doughs revealed no adverse effect on yeast performance (Merritt 1959) when used up to ten times the amount required for balanced sweetness.

Inactive Dried Yeast.—Non-living dried yeast must be processed especially for the baker's use to prevent excessive softening of dough due principally to the action of glutathione, a tri-peptide with a pronounced effect on gluten, resulting in poor gas retention. The accompanying defects, described by Ziegler (1956), are avoided by adequate oxidation of the heat-killed yeast prior to drum drying.

Growth of Yeast in Doughs

Indications of yeast growth, as evidenced by bud formation, were well-founded in the earlier studies of straight doughs made with compressed yeast (Hoffman *et al.* 1941). The commercial preference for sponge and dough methods, the ascendant development of brew processes, and the widespread use of active dry yeast has occasioned a re-examination of yeast growth by Thorn and Ross (1960).

Their comparative study established that nearly all growth consisted of bud formation, most buds approached the size of the mother cell at the end of many dough fermentations. The size and number of buds observed suggested their importance as indicators of overall yeast performance.

Table 29

YEAST GROWTH IN SPONGE-DOUGH AND BREW-DOUGH[1]

		ADY[2]		CY[2]	
		Cells	Buds	Cells	Buds
Sponge:	Initial	329	4	434	7
	4 hours	323	119	456	230
Dough:	initial	214	81	273	139
	end proof	223	84	295	122
Brew[3]*:*	initial	1130	25	1510	58
	end 4 hours	1110	29	1550	37
Dough:	initial	284	6	386	5
	end proof	293	55	388	63

[1] Adapted in part from Thorn and Ross (1960).
[2] Millions of cells or buds per gram dough; averages of two experiments.
[3] Millions of cells or buds per ml.

Both yeasts, active dry and compressed, increased 35 per cent in straight doughs fermented 3 to 3.5 hours, but no growth was found in sweet doughs or flour-based brews after four hours. Greatest growth, about 55 per cent, developed in sponges, while little change in cell counts developed during the dough stage and in the brew stage, as the summary in Table 29 shows. With brews of different composition and treatment, Masselli (1959) also observed that yeast activity was not enhanced in the 3 to 4 hours brew stage.

Budding was unaffected by the absence of air during mixing of experimental sponges or straight doughs (Thorn 1959). In synthetic sponges prepared with flour fractions according to Bechtel and Meisner (1954) yeast growth was dependent upon the tailings (mostly mechanically-damaged starch) and was stimulated by the water-soluble fraction.

YEAST GROWTH IN SYNTHETIC SPONGES

Flour Fraction	Buds at 4 Hours, Per cent	
	ADY	CY
Gluten + starch + tailings	44	40
Gluten + starch + tailings + solubles	58	49

Flavor

Bread flavor is derived from the components of the formula, the by-products of microbial action, and thermal effects of baking. In white bread the complex interactions result in a bland flavored product received with variable consumer preference and acceptance. The characterization of good bread flavor is difficult, but its judgment by a selected, discriminating panel is accomplished with reasonable success. Nevertheless, while research is slow it has been established that bread flavor is dependent to the greatest extent on fermentation and the baking process (Baker *et al.* 1953, Wiseblatt 1957, 1959, Chen 1954). The components of the formula, except for sugar, salt and mold inhibitor, normally contribute relatively little to the flavor of white bread sold today.

Bread flavor research is still in the analytical stage—determining the identity and content of compounds separated from oven condensate, bread crumb, bread crust and fermented solutions, and attempting to ascertain their origin. As yet no one has successfully achieved a recombination of purified fractions or chemicals to produce fresh bread flavor synthetically. Compounds detected repeatedly and their probable origin are tabulated below. The list could be extended considerably to include a host of trace compounds arrested in their transformation in the oven, but their role in the flavor profile would be most difficult to assess.

SOME FLAVORANTS FOUND IN WHITE BREAD[1]

Volatile		Non-volatile
Ethyl alcohol[2]	Furfural[3]	Ethyl lactate[3]
Acetaldehyde[2]	Acetic acid[2]	Ethyl succinate[3]
Crotonaldehyde[3]	Caproaldehyde	Succinic acid[2]
Pyruvaldehyde[2]	Pyruvic acid[1]	Lactic acid[2]
Acetoin[2]	Diacetyl[3]	Levulinic acid[3]
Acetone[2]	Dihydroxyacetone[2]	Melanoidins[3]

[1] From oven vapor condensate and steam distillates of fresh bread.
[2] Products of microbial metabolism.
[3] Believed formed during baking.

The aromatic characteristics of a few flavorants identified with bread flavor components are listed at the top of page 58.

There is a dearth of quantitative data on the compounds identified. Baker (1957) attributed the odor of fresh bread to diacetyl (the oxidation product of acetoin), ethyl alcohol, pyruvaldehyde, acetaldehyde, fur-

Compound	Aroma
Acetoin	Buttery
Furfural	Bread toast
Pyruvaldehyde	Burnt toast
Ethyl lactate	Rum-like
Ethyl succinate	Weakly pleasing

fural, iso-aldehydes, acetic acid and traces of esters; these were ranked in their likely order of importance. Acetoin or acetyl methyl carbinol, a fermentation product, fluctuates with the kind of dough process: little occurs in straight doughs, but substantial increases were found in bread from sponges and brews.

Wiseblatt and Kohn (1960) used estimates of amounts of volatile compounds recovered from warm, shredded, fresh bread by vacuum pumping as a basis for compounding a flavor for adding to a bland, chemically-leavened product. The volatiles tested failed to enhance flavor whether incorporated directly into the test dough or added to its slices by fumigation.

In contrast Chen (1954) obtained an oily fraction during steam distillation above 185 F. of a cell-free broth separated from a 24-hour bakers' yeast fermentation of a complete synthetic medium. This fraction had an odor similar to that of fresh bread crumb. It contained principally higher alcohols—iso-amyl, N-amyl, secondary butyl and tetrahydrofurfuryl alcohols. Incorporation of this fraction in a bland test dough resulted in a yeasty flavor of relatively low intensity.

Broths from four-hour fermentations of complex media imparted recognizable bread flavor to a chemically-leavened test loaf (Matz *et al.* 1958). The preferred flavor complex, as determined by panel judgment, was prepared by lyophylization of the centrifuged broth obtained from yeast fermentations conducted near pH 5.4 in the presence of high concentrations of sucrose (30 per cent), compressed yeast (15 per cent) and non-fat dry milk (15 per cent) in 0.1 molar disodium phosphate. Obviously any system providing ample yeast, sugar and time, the essentials of brisk fermentation, will produce bread flavor. The key question remains—how can good bread flavor be achieved with desired intensity and uniformity? What biochemical and biophysical modifications will soon aid the baker, whose keys to good flavor and palatability are prescribed now by the art as liberal yeast, adequate salt, work dough cool, ripen correctly and bake well?

Yeast substance itself has a characteristic odor and flavor which is diluted beyond recognition in the remaining ingredients of the formula. Yeast fat extracted on a pilot scale by Brasch (1951) had a strong yeast like taste and odor. Crude fat additions of 0.2 per cent to bread dough at the remix failed to produce a loaf different from the control in flavor and aroma.

Bacterial cell matter accompanying the yeast and other dough components, especially flour and nonfat dry milk, likewise is flavorless in doughs. Although large numbers of bacterial cells are found in doughs, their mass is roughly only one-fiftieth that of yeast. Thus 50 bacteria equal, on the average, the weight of one yeast cell. Bacterial activity, however, seems paramount to that of yeast for optimum flavor development. Carlin (1958, 1959) claims this commensalism of certain bacteria and yeast is essential to potent bread flavor. Yeast free of bacteria produced white bread consistently lower in flavor score than loaves made with any of the three brands of compressed yeast tested. In straight doughs Carlin found that equal numbers of pure lactic acid bacteria of yeast origin and pure yeast did not match the white bread flavor achieved with regular commercial yeast.

EFFECT OF PURE CULTURES OF LACTIC BACTERIA ON BREAD FLAVOR[1]

Cultures	Millions of Cells[2]		Flavor Score[3]
	Bacteria	Yeast	
Compressed yeast	11	250	7.2
Pure yeast	...	300	6.0
Pure yeast and	9	280	6.8
lactic bacteria	325	285	6.5

[1] Adapted from Carlin (1958).
[2] Count per gram of dough.
[3] At six days.

One of the seventeen different bacteria isolated from yeast produced superior bread flavor repeatedly when grown in a separate brew for 24 to 72 hours and added to sponges at the dough stage, the brew replacing about half of the water (Carlin 1959).

This bacterial culture, a member of the genus *Leuconostoc*, metabolizes sugar to carbon dioxide, ethyl alcohol, lactic acid, acetic acid and glycerol. In the same dough system lactic acid bacteria of the *Lactobacillus* group, also a common associate of bakers' yeast, improved bread flavor and odor significantly, confirming the earlier work on straight doughs. Robinson *et al.* (1958) obtained the best flavored bread when their yeast brews were fortified with lactobacilli, especially *Lactobacillus bulgaricus*, strain 09. This type of bacteria ferments sugar solely to lactic acid. A gross comparison of microbial by-products indicates a similarity of metabolism between yeast and the *Leuconostoc* species. Variations in quality and quantity of end-products will occur with changes in environment, thereby altering the flavor components or their precursors. Long ago Pasteur

FERMENTATION PRODUCTS OF BAKERS' YEAST AND ASSOCIATED BACTERIA[1]

Products	Bakers' Yeast	*Leuconostoc* Bacteria	*Lactobacillus* Bacteria
Carbon dioxide	47	21	0
Ethyl alcohol	48	23	0
Lactic acid	trace	31	100
Acetic acid	trace	8	0
Succinic acid	1	0	0
Glycerol	3	9	0
Unidentified	1	8	0

[1] Values are approximate per cent of glucose used.

(1874) pointed to the presence of products other than alcohol and carbon dioxide in yeast fermentation. When yeast action is slow, Pasteur found the proportion of glycerol and succinic acid to alcohol was higher than with a vigorous fermentation.

Sources of lactic acid bacteria other than bakers' yeast could be flour (Kent-Jones and Amos 1957) and non-fat dry milk.

Stimulation of flavor development rate in short-time doughs has not been fruitful. Faucette and Chen (1954) compared chemically-leavened doughs containing yeast and dihydroxyacetone, an intermediary product in yeast fermentation. Improvement of bread flavor was detected, but not reproducible, probably because the increase in fermentation rate was relatively small. In the normal dough fermentation, the rate of gas production reaches a constant value within a few minutes after mixing.

Overstimulation of fermentation by yeast and bacteria is detrimental to flavor as well as crumb structure. In an overripe dough, the combined effects of excessive microbial action could result in sour, soggy and yeasty bread (Swortfiguer 1950; Carlin 1959).

The final step in bread making, the baking, engenders flavor reactions, principally in the crust, essential to good flavor. The interaction of residual sugars and nitrogenous compounds yield a mixture of flavorants, the bitter, brown products termed melanoidins, and caramel polymers. Maillard-type condensations between reducing sugars and amino acids probably predominate. Baker (1957) believes other flavorful products originate in the browning reaction, such as pyruvaldehyde from pyrolytic sugar decomposition, isoaldehyde from amino acids and furfural from pentosans.

Accentuation of bread flavor quality by amino acid fortification of fermenting sponges has produced unpleasant effects. Baker *et al.* (1953) described the bread made with added leucine as cheese-like and unappetizing. Phenylalanine supplements yielded bread with the odor of pansies. Similar effects were noted by Fortmann (1959) upon heating a simple system of glucose and amino acids at 130° F., a temperature much lower than that reached at the crust during baking. Bread baked at 425 to 450°F. attains a crust temperature near 300°F., but only about 212°F. at the interior. The intensity of browning and odor differences observed by Fortmann are summmarized below:

ODOR AND COLOR OF GLUCOSE-AMINO ACID SOLUTIONS[1,2]

Amino Acid	Color	Odor
None (control)	0 (clear)	None
L-proline	1	Buttered popcorn
Phenylalanine	3	Pansy
L-leucine	4	Cheesy
L-tryptophane	5 (dark brown)	Burnt sugar

[1] From Fortmann (1959).
[2] After heating for 20 min. at 130°F. a solution containing 30 per cent glucose and 0.25 per cent amino acid.

The bland, neutral flavor of bread is, of course, one of its greatest attributes, anchoring its reputation as the *Staff of Life.* And it is reassuring to note that in food monotony studies today, white bread retains its preferred position. A group of 86 soldiers under test for 35 days didn't get "fed-up" with white bread, regardless of the number of repeated servings (Schutz and Pilgrim 1958).

COMMERCIAL BAKERS' YEAST

The manufacture of bakers' yeast is a singular example of a microorganism produced on a large scale for distribution as living, resting cells and used as such. Annual production exceeds 100 million dry pounds of bakers' yeast and over 36 million pounds of inactive dry yeast (Anon. 1954; Dunn 1958).

The process begins in the laboratory, employing a selected, proven strain of *Saccharomyces cerevisiae.* After several successive pure culture stages in different nutrient media of increasing quantity, the trade propagations are made in huge fermenters containing 20 to 30 thousand gallons of diluted molasses maintained at 86°F. During the course of yeast growth, precise regulation of pH, mineral additions, aeration rates and incremental feeding of dilute, sterilized molasses is required. As the strongly aerobic conditions prevail and the sugar, as molasses, is fed properly, the yeast converts the greatest proportion of the nutrients supplied to cell components, thereby increasing in weight and number of cells. Under optimum conditions 100 parts of hexose sugar yields 56.7 parts of yeast dry substance; or, 1.76 gm. glucose would produce 1.00 gm. yeast dry matter containing the following approximate proportions: 47 carbon, 33 oxygen, 8 nitrogen, 7 hydrogen and 5 ash.

Synthesis of a pound of active dry yeast, for example, requires 700 cu. ft. of air, 4 lbs. molasses, 0.8 lb. ammonia and 1.3 lbs. ammonium phosphate and sulfate. The quantities of air are large because the oxygen demanded by yeast for maximal growth is of very low solubility at fermentation temperatures. Other problems of aeration encountered in practice are discussed by Strohm *et al.* (1959).

Upon completion of the propagation, yeast is recovered and concentrated to a slurry of about 18 per cent dry solids by centrifugal methods and dried on an atmospheric drum drier to produce inactive dry yeast; or the cream is pressed to approximately 30 per cent solids. Such press cake may be packaged as compressed yeast for the baker, processed with starch for household use, or extruded as cylindrical segments for dehydration to eight per cent moisture, usually on a belt-type drier operated below 110°F.

For a more comprehensive discussion of yeast manufacture, two excellent texts are recommended: White (1954) and Pyke (1958).

Compressed Yeast

The principal market forms of compressed yeast are 3/5 oz., 2/3 oz., 1 oz., and 2 oz. for household use, 1-lb. and 5-lb. blocks for the baker (Fig. 17). The one-pound block measures 2.5 × 2.5 × 4.5 inches, approximately.

Though perishable, compressed yeast loses little fermentation power during refrigeration (40°F.) for 4 to 5 weeks, and it can be stored in the frozen state (−25°F.) for months. Merritt (1959) compared the change in proof time after such storage; part of his data obtained on straight doughs is given below.

MINUTES GAINED IN PROOF AND TOTAL TIME

Weeks Stored	40°F.		−25°F.	
	Proof	Total Time	Proof	Total Time
2	1	6	3	6
4	2	19	5	22
6	7	44	7	15
12	13	118	3	10
19	31	233	4	17

In composition the major brands of commercial yeast range from 8 to 9 per cent nitrogen, 1.0 to 1.4 per cent phosphorus, 69 to 71 per cent moisture, and 20 to 24 billion cells per wet gram. Bacterial content varies considerably, but usually is less than 500 million per wet gram, as determined by a differential plate count employing actidione or amidomycin (Green and Gray 1950; Taber and Vining 1957). Compressed yeast has a light, cream-like color which can be measured reflectometrically. Upon extended storage, surface mold growth may appear.

The uniformity of compressed yeast performance is illustrated in the following summary of an annual accumulation of bake tests on samples from four major producers.

Manufacturer	Per cent Activity *vs.* Reference Yeast		
	Sponge	Straight	Sweet
A	126	136	84
B	129	145	91
C	128	144	93
D	127	140	90
Number of samples	27	50	15

Active Dry Yeast

Dehydration of the cylindrical segments obtained by extrusion is accomplished within six hours on a Proctor and Schwartz belt drier regulated in air flow, humidity and moderate temperatures to yield a light-tan "noodle," friable and of mild odor. Excessive temperatures and holding during drying may lead to impaired cell permeability, effecting a loss of vital cell components upon subsequent rehydration (Peppler and Rudert 1953; Herrera *et al.* 1956). The unground product, Fig. 18, is channeled to the baker in 10 to 300 lb. fiber drums. A free-flowing, granular ADY, obtained by passage through a Burns or Fitz mill, is packaged for the consumer, mix packer and bulk users equipped to handle flexible drums.

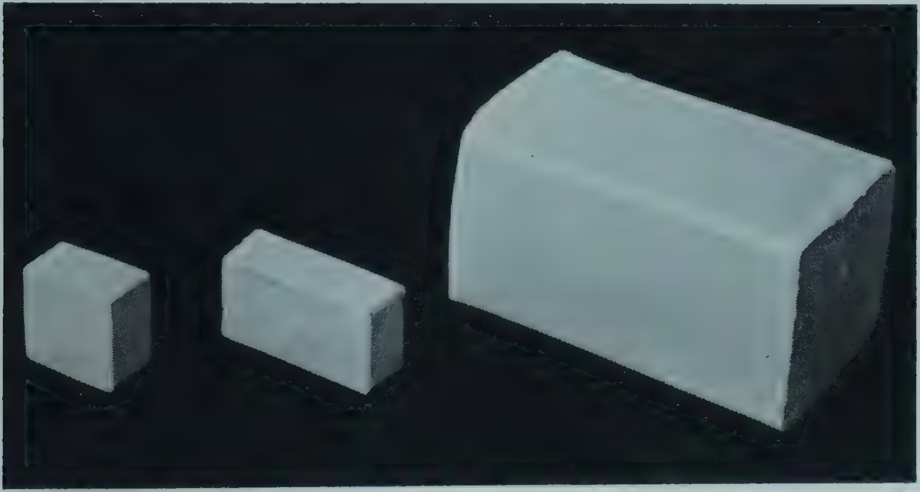


Fig. 17. Compressed Yeasts $^{2}/_{3}$ oz., 1 oz., and 1 lb. Sizes Unwrapped

Active dry yeast is packed in a variety of containers, depending upon its ultimate use and shelf-life desired. Air packs of fiber drums, 10 to 300 lb., are used generally in the baking trade, but an average yeast activity loss of seven per cent per month is experienced in the field. Greatly improved shelf-life is achieved through vacuum and nitrogen packing. Carbon dioxide is unsuited for this purpose (Amsz *et al.* 1956).

Felsher *et al.* (1955) stored vacuum-packed ADY at temperatures ranging from −20° to 120° F. Their data, being typical of nitrogen and vacuum protection, revealed the greatest shelf-life at the lowest temperature; they also found that freezing temperatures, or alternate freezing and thawing cycles, were harmless to baking quality:

Storage Temperature, °F	Usable For Months	Storage Temperature, °F	Usable For Months
40	24+	90	6
70	21	120	1/4

Thermostability and shelf-life of active dry yeast can be improved by drying to 5.5, 4.0 and 2.2 per cent moisture followed by vapor rehydration to eight per cent moisture before use, or by incorporation of a lipophilic sorbitan ester with yeast before dehydration (Mitchell and Enright 1957, 1959). Neither procedure has been brought into commercial practice.

Vacuum-packed cans containing 4 oz., 8 oz., 2 lbs., and 25 lbs. ADY are presently marketed. Nitrogen-packed ADY is offered in two types of packages: paper-foil-pliofilm pouches containing 5 to 42 gm. yeast, and flexible drums of 1800 to 2700 lbs. capacity. Suitable methods for microgas analysis have been developed by Dale (1956A, 1956B).

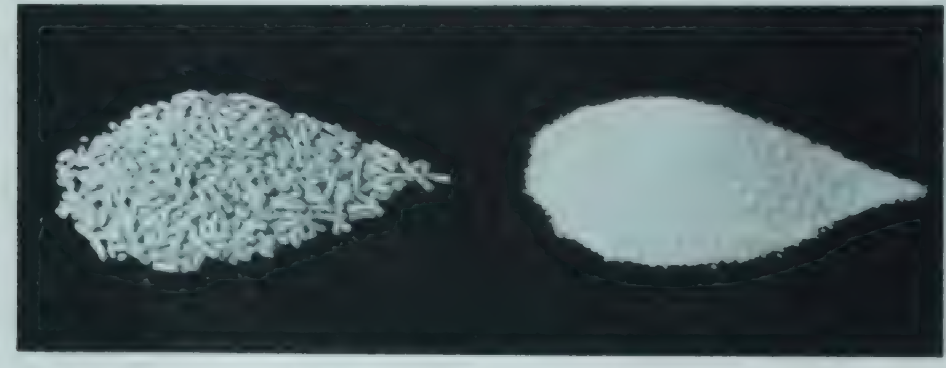


FIG. 18. ACTIVE DRY YEAST, UNGROUND (LEFT) AND GRANULAR

Shipment and storage of ADY without refrigeration is the common practice because of its low moisture content and marked performance stability. However, paper thermometers are useful monitors in handling and transporting ADY at ambient temperatures (Peppler and Dale 1958).

Field samples of ADY range in nitrogen content from 6.2 to 7.3 per cent and moisture of 7.4 to 8.5 per cent, the average differing for each producer (Thorn and Reed 1959). Product destined for Federal agencies must meet the following specifications (Anon. 1956): not exceed 8.3 per cent moisture nor exceed a rope spore count of 200 per gram. No mold spoilage is encountered except under extreme conditions of moisture absorption. Aside from the possible presence of rope spores (*Bacillus mesentericus* group), ADY is relatively low in associated bacteria of the lactic group, averaging below 100 million per gram, determined on actidione differential agar as cited above.

For optimal results a rehydration temperature of 100° to 115°F. is recommended. Higher temperatures will inactivate yeast enzymes, while lower temperatures progressively increase the removal or leaching of normal cellular constituents (Herrera *et al.* 1956; Sant and Peterson 1958; Thorn and Reed 1959). One of these compounds, reduced glutathione, is responsible for the "proteolytic" effect on gluten. In relatively low concentrations it is beneficial, shortening the mixing time of strong flours by several minutes. Excess glutathione, as released from aged yeast, overdried yeast, or by low temperature rehydration, produces slackening of doughs, which is preventable, however, with increased yeast food usage to achieve additional oxidation. At 40°F. four times as much of the active tripeptide is extracted than at 110°F. The normal yeast content of glutathione is 7 to 12 mg. per gram; Schultz and Swift (1955) claim the development of a yeast strain with only one-half this content, and capable of metabolizing the tri-peptide, thereby minimizing its "proteolytic" potential. Subsequent experience in production control to avoid damage during drying of ADY and its storage has obviated such hybrid development in practice.

Compact devices with provisions for tempered water, agitation and pressure discharge are available to aid the baker in rehydrating and dispersing ADY. Automatic units metering pre-selected quantities of warm water, ADY, yeast food and enrichment tablets are being field tested. They handle from 10 to 20 lbs. ADY dispersed in water at optimum temperature.

Inactive Dry Yeast

Inactive dry yeast is of three types, but all are heat-killed products which, for the baker, must be given an oxidation treatment, usually with bromate. When bakers' yeast is used to make this product it is designated primary dried yeast (Anon. 1955), as distinguished from processed brewers' yeast, which is also classified with primary grown yeast in the U. S. Pharmacopoeia as "Dried Yeast (*Saccharomyces cerevisiae*)." The third type of inactive dry yeast is listed in the U. S. Pharmacopoeia as "Dried Torula Yeast (*Candida utilis*)." Its use in standardized bread is restricted by bread standards (Anon. 1952); but its use in rye bread has resulted in enhanced flavor qualities.

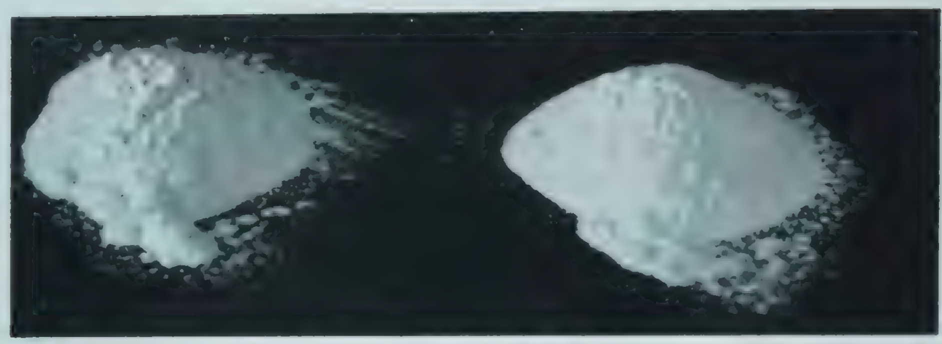


FIG. 19. INACTIVE YEAST: DRIED YEAST, U.S.P. (LEFT) AND DRIED TORULA YEAST, U.S.P.

All three products bear identical U.S.P. specifications with respect to protein, moisture, ash, vitamin, bacteria and mold content. Two types of inactive dry yeast powder are shown in Fig. 19. The usual screen analysis of such powders produced with the Fitz mill is as follows: 70 per cent through 120 mesh, 15 per cent on 120 mesh, 9 per cent on 80 mesh, the remainder on 60 mesh.

Performance Tests

A variety of methods can be used in quality control to determine the relative rates of carbon dioxide formation of fresh bakers' yeast. But none achieves the reliability and versatility afforded by standard baking tests, for only they truly measure the changes in yeast stability. The degree of change, reflected in the production of gas and its retention, can be judged with reference to the performance of a standard yeast tested simultaneously. A reference yeast such as active dry yeast, vacuum-packed and refrigerated, retains its activity undiminished for more than one year, allowing advantageous comparisons of daily data and long range trends.

Dough Methods

Proven basic formulas suitable for laboratory baking tests on all yeasts are compiled in Table 30. Methods in common practice among bakers are employed in the preparation, handling and observation of the doughs. A typical bake laboratory is maintained uniformly at 82° F. and a relative humidity of 35+ per cent. Straight doughs may be fermented in glass, cylindrical jars (5 in. × 7 in.) capped loosely with a metal cover fitted with a gauge calibrated to mark the desired volume to be reached by the expanding dough. After three rises, it passes through a loaf molder and is pan-proofed to the prescribed height in a cabinet controlled at 95° to 96° F. and a relative humidity of 90 per cent.

TABLE 30

REPRESENTATIVE DOUGH FORMULAS FOR TESTING YEAST ACTIVITY

Ingredients[1]	Straight	Sponge[1]		and Dough[1]	
Flour: Northwest spring	400	800	*1040*	400	*240*
Southwest winter	. . .	800	. . .	400	. . .
Pastry	. . .	. . .	. . .	. . .	*320*
Water: with CY or	280	1000	*685*	600	*80*
with ADY	280	1060	*685*	600	*135*
Yeast: CY or	8	54	*96*	. . .	. . .
ADY	2.7	21.6	*38.4*	. . .	. . .
Yeast Food: CY or	. . .	9	*8.0*	. . .	. . .
ADY	. . .	12	*8.0*	. . .	. . .
Salt	8	. . .	. . .	48	*24*
Sugar	16	. . .	. . .	96	*320*
Nonfat milk solids	16	. . .	. . .	96	*64*
Shortening	12	. . .	. . .	72	*240*
Eggs, whole, fresh	. . .	. . .	. . .	. . .	*240*
Conditions					
Mixing; minutes; low + high, CY or	0.5 + 3.5	2 + 3	*2 + 3*	2 + 6	*1 + 7*
ADY	0.5 + 3.5	2 + 3	*2 + 3*	2 + 5	*1 + 4*
Temperature out, °F.	80	78 to 80	*80*	80	*80*
Temperature back, °F.	. . .	90	*88*	. . .	. . .
Fermentation time, hrs.	3 rises to 1,000 ml.	4	*3.5*	. . .	. . .
Floor time, min.	. . .	. . .	. . .	20	none
Bench time, min.	. . .	. . .	. . .	18	*20*
Baking temp., °F.	425	. . .	. . .	410	*375*
Baking time, min.	25	. . .	. . .	25	*25*

[1] Values in italics are for sweet dough formula.

This typical laboratory will also be suitable for sponge-dough tests: the sponge fermentation, floor time and intermediate proof conducted at 82°F., and pan-proof in the cabinet at 95°F.

Yeast strength can be expressed in terms of the reference yeast performance. For straight doughs the activity may be determined from the quotient of the total minutes of three rises for the reference yeast and the test sample; thus,

$$\frac{\text{Total Time (reference)}}{\text{Total Time (sample)}} \times 100 = \text{per cent activity}$$

Similar expression can be given to sponge-dough proof times.

Under conditions requiring yeast activity tests where baking facilities are lacking, modifications of the straight dough procedure, anchored to the baking test data of the given establishment, are helpful. Total time can be calculated from the first rise of the test sample as compared with the reference standard. Or, an adaptation of the Sandstedt-Blish pressuremeter system (1934) held at 86°F., illustrated in Fig. 20, has been found to correlate very well with baking activity of straight doughs (Thorn and

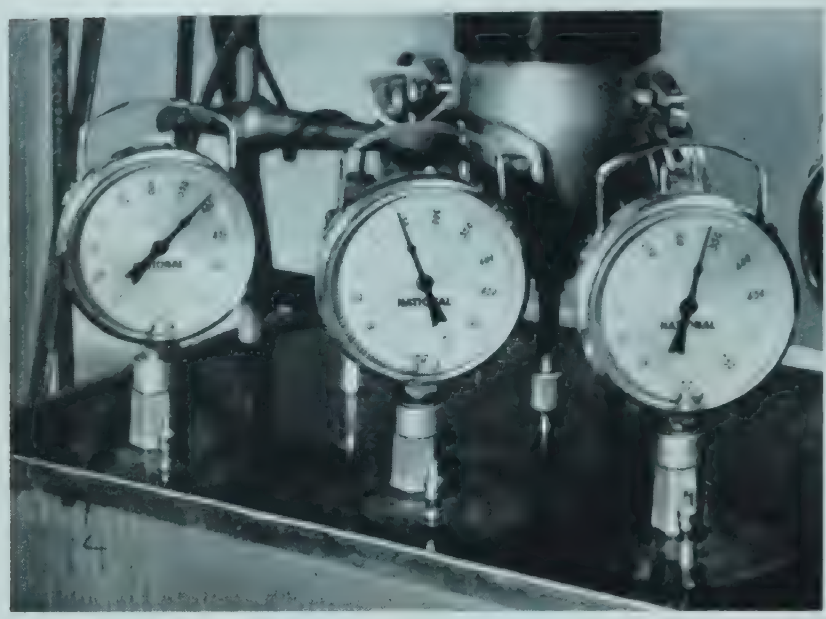


Fig. 20. Pressuremeter Method for Testing Yeast Activity

Reed 1959). The modification involved changes in the recommended dough composition of flour, water and yeast (Swanson 1957) to provide the same concentration of yeast, sugar and salt as used in the straight dough. Typical results for two test conditions appear below (Thorn 1959).

Yeast	Proof Time[1]		Total Time[1]	
	Found[2]	Estimated[3]	Found[2]	Estimated[3]
Compressed	49	51	171	168
Active dry	62	61	210	210

[1] In minutes
[2] Actual straight dough test
[3] From gas pressure-time curves

A new method proposed by Burrows and Harrison (1959) measures gas evolution from a small volume of thin dough suspended in fermentation bottles held at constant temperature. Although precision greater than that of the baking test is claimed, their "fermentometer" method is more complex in its material and apparatus requirements than the Sandstedt-Blish pressuremeter.

Several instruments of novel and often complex design have appeared, chiefly in Europe, for gasometric measurements on fermenting doughs and their recording. Kent-Jones and Amos (1957) have described the following in moderate detail: *Chefaro Balance*, a Dutch device which automatically weighs and records gas production and retention, *Chopin Zymotachegraph*, a completely automatic system recording gas formed and escaping from doughs every 2.5 min. at 90.6° F., *Fermentograph*

(Brabender), places the dough in a balloon attached to a counter-balance weight; *Volumetograph*, an ordinary gasometer with a recording pen coupled to a water-sealed bell which rises as the dough ferments.

Sugar Solutions

Yeast activity in chemically-defined sugar media is determined either in a fermentometer (Schultz *et al.* 1942, Atkin *et al.* 1945) or a microrespirometer of the Warburg type. These systems, while useful for comparative studies of yeast biochemistry, are limited in their application to problems faced by the yeast testing laboratory. In the evaluation of active dry yeast, for example, liquid systems yield results which usually correlate poorly with the data on the same sample tested in doughs.

Special Tests

Active dry yeast destined for certain Federal agencies must comply with prescribed specifications based on a modified straight dough baking procedure (Anon. 1956). The test is made on the active dry yeast sample and the standard active dry yeast supplied, after both are exposed to 115°F. for 96 hours. The time required for the standard yeast to reach 1400 ml. at 86°F. is the time at which all test samples are removed for further processing. This single rise is followed by a rest period of 15 minutes at 86°F., molding and pan-proofing at 96°F. All doughs are allowed to proof for the same time established by the standard yeast to attain the prescribed height in the pan. After baking the test yeast and the standard yeast loaves for exactly the same length of time at 450°F., the loaf volume, determined after one hour of cooling, is the principal criterion of yeast quality. The sample of yeast meets specifications if it attains a bread loaf volume which is not less than 92 per cent of that produced by the standard active dry yeast in parallel test.

Adequate oxidation of inactive dry yeast intended for the bakers' use is readily determined chemically; however, a laboratory bake test is often made for assurance. For this the straight dough method is a convenience for most bake laboratories. Doughs prepared with as much as five per cent specially-treated inactive dry yeast are compared with an unsupplemented control worked in the normal manner. When the volume of the loaf containing inactive dry yeast is within 100 ml. of the control, the test sample is considered free of reducing substances effecting slackness in doughs.

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CHAPTER 3

John A. Maselli

Water

GENERAL DESCRIPTION

Water is a chemical compound resulting from the combination of two atoms of hydrogen and one atom of oxygen and is thus expressed chemically as H_2O. In its pure form, water is a tasteless, odorless, and colorless liquid. However, because water has such excellent dissolving properties and since practically all substances are water soluble to some degree, it is almost never found in nature as a pure substance. Water always tends to carry gases and inorganic and organic substances with it, in finely divided suspensions, or in solution. These suspended and dissolved materials are of importance to bakers because of their effects on doughs and on processing equipment (steam boilers, water jackets, etc.).

Our primary water reservoirs are our oceans, from whence most of our water originates and to which most of it returns. This cycling process is not unlike a huge distilling apparatus. Water from our oceans, when heated at the surface of the oceans by the sun, is converted to water vapor. Since it is less dense than liquid water, the vapor rises from the oceans, through the atmosphere, and eventually accumulates in clouds. When the clouds are cooled by contact with cold air currents, the result is condensation from the less dense vapor to the denser rain or snow.

From the time that condensation of the chemically pure water vapor occurs, until the time that the water reaches our water treatment equipment, the water is becoming more and more contaminated with gases, and suspended or dissolved inorganic and organic materials. The cycling process of water distilled from the ocean, the intermediate contamination, and the redistillation from the ocean is shown in Fig. 21 (Powell 1954).

The type and extent of the contamination of condensed water vapor depends on the purity of the air through which the rain or snow falls and the composition of the earth over which the surface waters run, or through which the underground waters travel. Rain water collected in rural districts is relatively free of contaminants. On the other hand, rain water collected in large industrial areas is more likely to contain a greater amount of contaminants from the atmosphere (Fig. 22).

After the rain water hits the ground, it comes into further contact with minerals and metals in the earth and continues to dissolve these substances.

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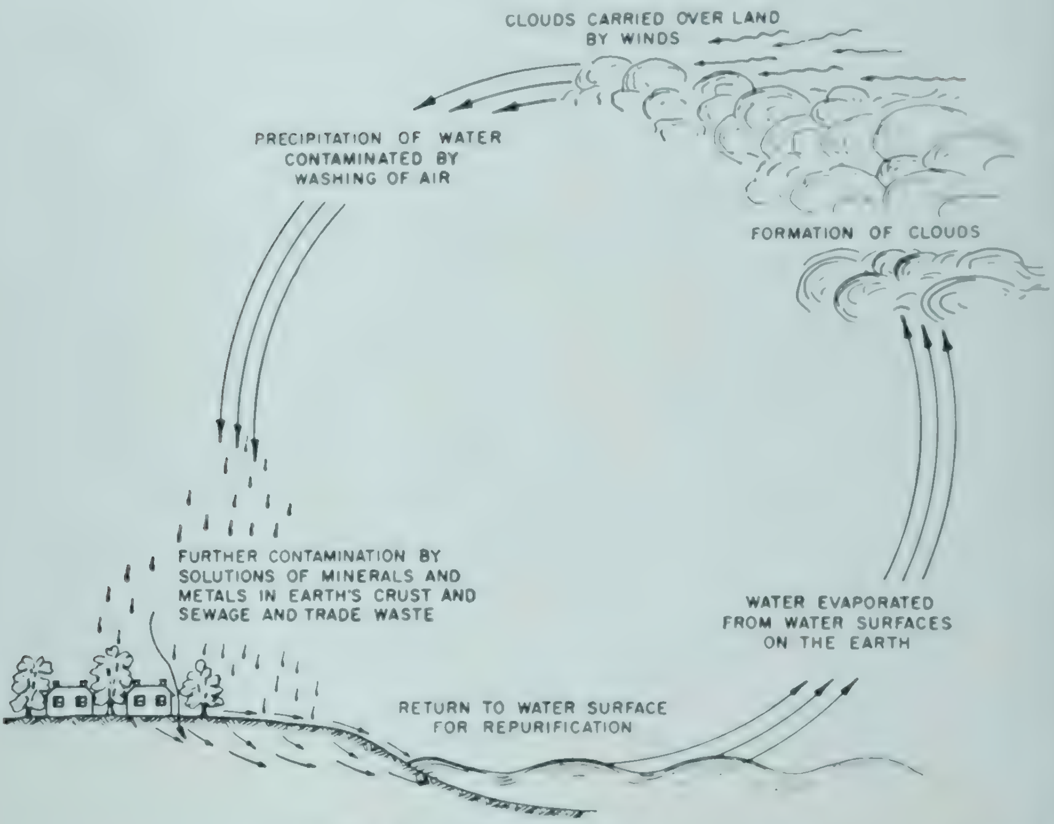
CLOUDS CARRIED OVER LAND BY WINDS
PRECIPITATION OF WATER CONTAMINATED BY WASHING OF AIR
FORMATION OF CLOUDS
FURTHER CONTAMINATION BY SOLUTIONS OF MINERALS AND METALS IN EARTH'S CRUST AND SEWAGE AND TRADE WASTE
WATER EVAPORATED FROM WATER SURFACES ON THE EARTH
RETURN TO WATER SURFACE FOR REPURIFICATION

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FIG. 21. DIAGRAMMATIC REPRESENTATION OF THE CONTAMINATION AND RE-PURIFICATION OF A NATURAL WATER SUPPLY

The solvent action of the water is increased by the presence of dissolved gases, of which the most important are carbon dioxide and oxygen. Carbonic acid, resulting from the solution of carbon dioxide in water is weakly acidic and tends to increase the rate of solution of minerals and metals found in the earth. A further source of contamination, usually organic in nature, results from the discharge of sanitary sewage and industrial waste into the water supply. As a result of these conditions, water that is collected in springs, wells, lakes, rivers, etc., is not a pure chemical compound, but is a complex system containing many dissolved or suspended substances.

COMMON WATER IMPURITIES

The common water impurities and the means that are used to remove them from water are summarized in Table 31 (Powell 1954).

In addition to the common impurities shown in Table 31, other mineral constituents which quite frequently occur in natural waters are salts of iron, aluminum, potassium, and lithium as well as traces of the salts of

TABLE 31

COMMON IMPURITIES IN WATER[1]

Constituent	Chemical Formula	Principal Source of Contaminating Substances	Treatment for Removal from Water
Suspended solids	. . .	Surface drainage, industrial wastes	Plain subsidence, coagulation, filtration, evaporation
Silica	SiO_2	Mineral deposits	Plain subsidence, coagulation, filtration, evaporation
Calcium carbonate	$CaCO_3$	Mineral deposits	Softening by chemicals, ion-exchange materials, evaporators
Calcium bicarbonate	$Ca[HCO_3]_2$	Mineral deposits	Softening by heaters, chemicals, ion-exchange materials, evaporators
Calcium sulfate	$CaSO_4$	Mineral deposits	Softening by chemicals, ion-exchange materials, evaporators
Calcium chloride	$CaCl_2$	Mineral deposits	Softening by chemicals, ion-exchange materials, evaporators
Magnesium carbonate	$MgCO_3$	Mineral deposits	Softening by chemicals, ion-exchange materials, evaporators
Magnesium bicarbonate	$Mg[HCO_3]_2$	Mineral deposits	Softening by chemicals, ion-exchange materials, evaporators
Magnesium chloride	$MgCl_2$	Mineral deposits	Softening by chemicals, ion-exchange materials, evaporators
Free acids	HCl, H_2SO_4	Mine drainage, industrial wastes	Neutralizing, followed at times by softening or evaporation
Sodium chloride	$NaCl$	Sewage, industrial wastes, mineral deposits	Evaporation and demineralization by ion-exchange materials
Sodium carbonate	Na_2CO_3	Mineral deposits	Evaporation and demineralization by ion-exchange materials
Sodium bicarbonate	$NaHCO_3$	Mineral deposits	Evaporation and demineralization by ion-exchange materials
Carbonic acid	H_2CO_3	Absorption from the atmosphere, mineral deposits, decomposition of organic matter	De-aeration
Oxygen	O_2	Absorption from the atmosphere	De-aeration
Grease and oil	. . .	Industrial wastes	Coagulation, filtration, evaporation
Organic matter and sewage	. . .	Domestic and industrial wastes	Coagulation, filtration, evaporation

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[1] By permission from "Water Conditioning for Industry," by Powell (1954).

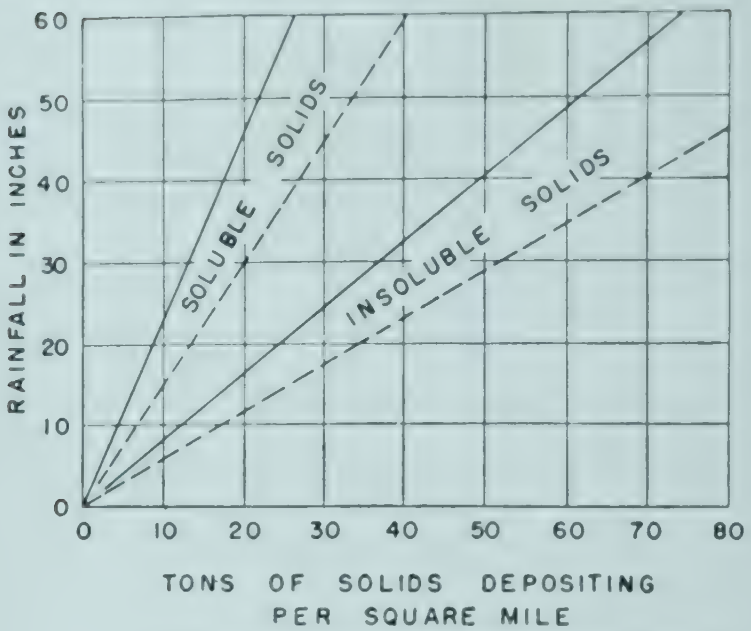

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FIG. 22. SOLIDS WASHED FROM THE ATMOSPHERE IN URBAN AREAS (DASHED LINES) AND SUBURBAN AREAS (SOLID LINES)

ammonia, antimony, arsenic, barium, boron, bromine, cesium, chlorine, cobalt, copper, fluorine, iodine, lead, rubidium, strontium and zinc (Brooke 1939A).

TABLE 32

CLASSIFICATION OF WATER HARDNESS[1]

Hardness	Classification
0 to 15 p.p.m.	Very soft water
15 to 50 p.p.m.	Soft water
50 to 100 p.p.m.	Medium hard water
100 to 200 p.p.m.	Hard water
Greater than 200 p.p.m.	Very hard water

[1] Betz and Betz (1945).

MINERAL CONTAMINANTS

Water is generally classified as hard or soft, acid or alkaline, depending on the substances dissolved in it. The hardness of the water is due primarily to the presence of iron, aluminum, mineral or organic acids, and some other metals. All of these substances are considered to harden water as indicated by their soap lather destructive properties.

The degree of hardness in water is measured by adding small quantities of a soap solution of standard strength to a water sample with vigorous shaking after each addition, all done under controlled conditions.

until a soap lather persists for a standard length of time. The total hardness which can then be calculated, is a measure of calcium, magnesium, and all other soap-destroying substances that are present in the water sample.

Natural water has thus been classified into degrees of hardness as shown in Table 32 (Betz and Betz 1945).

The concentrations expressed in Table 32 are as parts per million of calcium carbonate equivalent to all the calcium, magnesium, and other constituents that contribute to hardness.

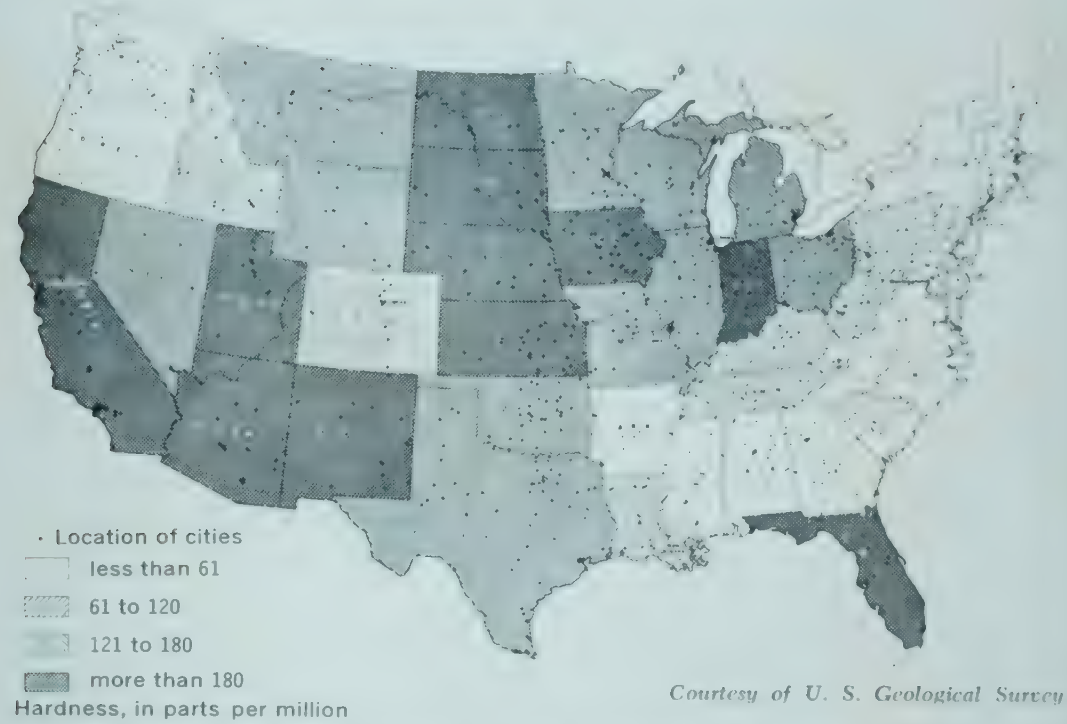
Permanent hardness means all hardness except that contributed by carbonates and bicarbonates. Carbonate hardness (formerly known as temporary hardness) is caused by the carbonates and bicarbonates of calcium and magnesium. Carbonate hardness can be overcome by heating, with breakdown of the soluble calcium and magnesium bicarbonates to the insoluble carbonate salts which precipitate from solution and no longer contribute to hardness.

The amount of hardness that is present in natural water varies widely throughout the world and obviously depends on the substances with which the water can come into contact. The average degrees of hardness that can be expected to occur in the raw waters and in the finished waters of the United States are shown in the maps prepared by the U. S. Geological Survey (Figs. 23 and 24).

The hardness of water is not to be confused with its soluble solids content. The latter is obtained by evaporating a measured amount of water and determining the weight of the residue. Sodium salts are a major constituent of soluble solids that do not contribute to hardness. The sodium compounds (chloride, carbonate, bicarbonate, hydroxide, sulphate and nitrate) are highly soluble in water and are generally without affect on water equipment.

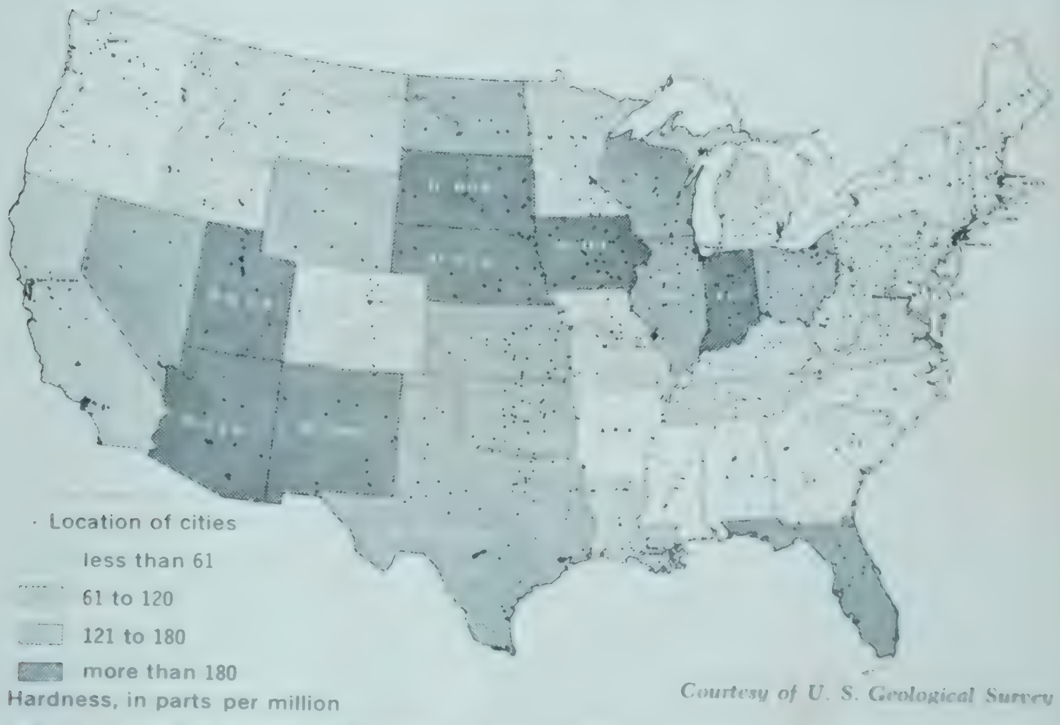
The hardness or softness of water used in bakeries can be important factors in the softness and pliability of doughs and the fermentative activity of the yeast in doughs, with resultant effects on bread quality. The degree of hardness of bakery water is an important factor in boiler scale and the corrosion of water-containing and water-carrying apparatus. These factors are covered in greater detail later.

The alkalinity of water is caused by dissolved alkaline substances such as carbonates and hydroxides. Water alkalinity can be an influencing factor in the pH of bread doughs and as such is an important consideration in fermentative activity and in rope prevention, as will be discussed in detail in a later section of this chapter. By the same token, acidic water caused by dissolved acids has an influence on the choice of bread formulas that bakers use.


· Location of cities
less than 61
61 to 120
121 to 180
more than 180
Hardness, in parts per million

Courtesy of U. S. Geological Survey

FIG. 23. MAP SHOWING WEIGHTED AVERAGE HARDNESS, BY STATES, OF RAW WATER FROM PUBLIC SUPPLIES FOR 1,315 OF THE LARGER CITIES IN THE UNITED STATES DURING 1952


· Location of cities
less than 61
61 to 120
121 to 180
more than 180
Hardness, in parts per million

Courtesy of U. S. Geological Survey

FIG. 24. MAP SHOWING WEIGHTED AVERAGE HARDNESS, BY STATES, OF FINISHED WATER FOR PUBLIC SUPPLIES FOR 1,315 OF THE LARGEST CITIES IN THE UNITED STATES DURING 1952.

ORGANIC IMPURITIES

The organic impurities that are found in water are generally due to local environmental conditions and are not as specific in types and amounts as are the metals, mineral salts, and gases. Organic contaminants can consist of many substances such as sewage, industrial waste products, algae, grease and oil, etc. Most of these substances are removed from water by settling or by coagulation and filtration.

Organic substances have a tendency to contribute off-flavors and off-odors to water; however the treatment of water by municipal plants usually effectively removes organic contaminants from the water supply. It may generally be taken for granted that municipally treated water is safe from a bacteriological standpoint and free from offensive flavor and odor.

WATER ADDITIVES

Two substances that are most commonly added to water are chlorine and fluorine salts.

Chlorination of water is generally accomplished by the addition of chlorine gas. Its main function is to control algae and bacteria in water used for drinking and in foods and for most industrial purposes. The efficient performance of water-purification equipment, such as flocculators, precipitators, filters, softeners, and aerators requires that the water be free of slime-forming bacteria, corrosive anaerobic bacteria, and gas-forming bacteria. Chlorination, in addition to helping to render water potable, effectively eliminates bacteria that affect water-purification equipment.

The amount of chlorine added to water varies, depending on the amounts of micro-organisms that are present in the water; however, the amounts that are generally used result in a residual concentration of about 0.2 p.p.m. At this level, chlorine does not affect yeast fermentations or dough properties.

Fluoride is added to the water in some municipalities as a tooth decay preventive. It is generally added as its sodium salt, in a concentration of about 1 p.p.m. Fluoride at the levels used in water has not been found to have any effect on doughs.

WATER TREATMENT

There are hardly any industrial operations in existence today that are not dependent on a reliable source of properly conditioned water. Conditioning is accomplished in most large cities and communities to an extent where the industrial user recognizes that the water supply can be generally expected to fall within certain specifications. If individual specifications necessitate that additional treatment be carried out, it can usually be done within the industrial plant.

Bakeries in most large cities can usually rely on the municipal water supply to be adequate. There may be certain formula adjustments, procedural changes, and equipment cleaning programs required for specific types of water. These changes or programs will generally compensate for the distinctive water types in large cities. This situation might be less prevalent in smaller cities or in plants which may be dependent on private water supplies. Some types of private water purification systems may be necessary in the latter case. Private water purification systems are becoming more and more common and economical; having reached the private home level to a large extent.

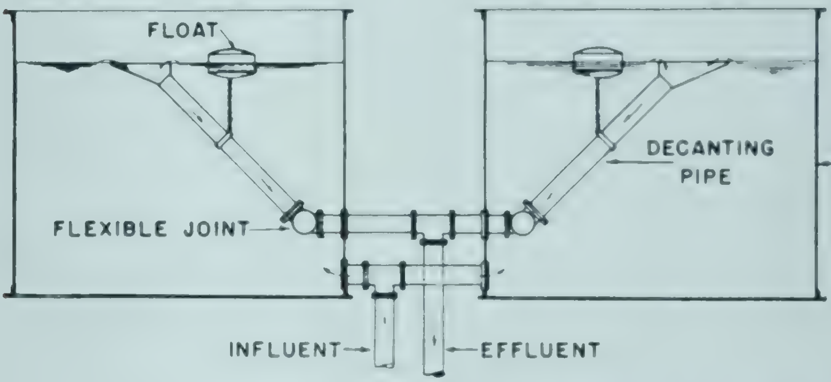


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FIG. 25. FILL- AND DRAW-TANKS FOR INTERMITTENT SEDIMENTATION

The most common water treatment methods and their chief functions are described briefly as follows:

Settling, Coagulation, and Filtration for Removal of Suspended Solids

Suspended solids that can be present in natural waters include grease and oil, organic matter and sewage, various other industrial wastes, clay, and silica.

Settling is usually used as the first step in water treatment to remove suspended solids. Settling basins of either the continuous or intermittent type are generally employed for this purpose. The efficiency of these tanks or basins depends upon the type and amount of solids in the water, the particle size of the solids and the time allowed for settling. A typical paired tank arrangement, in which one tank is filled while the other is supplying clarified water is shown in Fig. 25 (Powell 1954).

Water is admitted into the bottom of one of these tanks and after the required settling time, it is withdrawn through a "swing" pipe at a point just below the surface of the water. Settling in tanks of this type usually results in the removal of 30 to 90 per cent of the suspended solids.

Since settling alone can only remove relatively coarse materials within reasonable times it is usually combined with or followed by chemical coagulation for the removal of more finely divided particles, particularly those in the colloidal range of size. Colloidal particles tend to be extremely fine. For example, a non-colloidal particle such as would occur in fine sand might range in diameter from 0.1 to 1 mm., while a colloidal particle of clay may range from 0.000001 to 0.0001 mm. in diameter. These extremely fine particles tend to carry electrical charges of like potential which keep them in suspension. Hence, for their removal from water the charges must be dispelled and the fine particles must be coagulated or agglomerated into coarser materials so that they can settle or be filtered from the water. The coagulation is usually accomplished in reasonable time periods by adding to the water coagulants, such as aluminum and iron salts, ammonia and potassium alum, chlorinated copperas (mixtures of ferric sulfate and ferric chloride), sodium aluminate, activated silica, bentonite clays, processed starches, and miscellaneous compounds. These coagulants are generally fed into coagulating and settling basins where they are well mixed with the water. The resulting coagulation gives large sponge-like or jelly-like masses which contain the colloidal particles as well as any coarser particles that may have been present in the water.

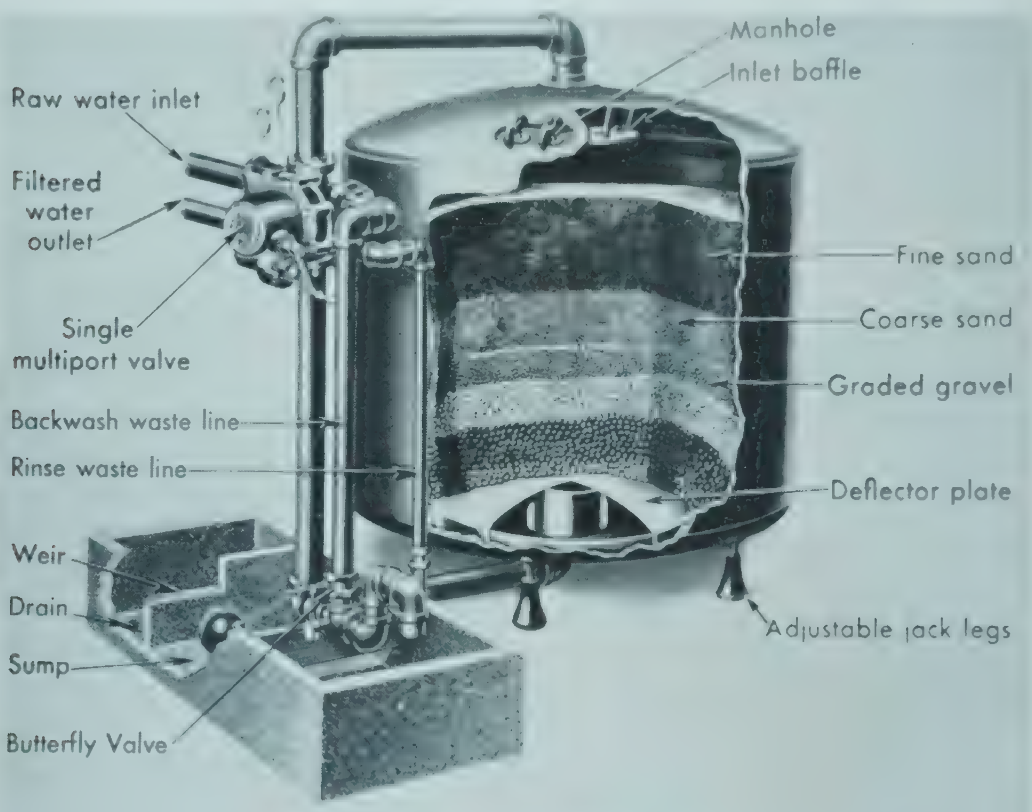
These solids can be allowed to settle to the bottom of the tank and the clear water can be removed from the surface or more commonly, the solids can be filtered from the water.

Filtration is generally used to remove the coarse solids that can be naturally present in water or that have been accumulated by settling or coagulation. Rapid sand filters are most commonly used. In addition, diatomaceous earth filters, precoated plate-type pressure filters, and anthracite coal filters are in use in many water-treatment plants. Activated carbon filters are sometimes used to remove tastes and odors from water.

A typical vertical-type pressure hand filter is shown in Fig. 26. After a definite amount of filtered solids has accumulated in the spaces between the sand particles, it is removed by pressure "back-washing" of the filter bed with filtered water.

Water Softening by Chemicals and Ion-Exchange to Remove Water Hardeners

As mentioned previously (p. 79) water hardness is caused primarily by calcium and magnesium salts, such as the bicarbonates, carbonates, sulfates, chlorides and nitrates. Since these substances can form scale on boiler equipment or can corrode pipes and water containers they are often removed to a certain extent in municipal water treatment plants especially in areas in which the degree of water hardness may be high. Since water hardeners are soluble, they are not removed to any significant extent by the methods previously described (settling, coagulation, or filtration) but they can be removed by the use of chemicals (lime-soda softening) or by ion-exchange (zeolite softening).


Raw water inlet
Filtered water outlet
Single multiport valve
Backwash waste line
Rinse waste line
Weir
Drain
Sump
Butterfly Valve
Manhole
Inlet baffle
Fine sand
Coarse sand
Graded gravel
Deflector plate
Adjustable jack legs

Permutit Vertical Pressure Filter
(Multiport Valve Control)
Type F

Courtesy of The Permutit Company

FIG. 26. VERTICAL FILTER SHOWING ARRANGEMENT OF FILTER MEDIUM

The lime-soda softening process can be done by the "cold-process" or the "hot-process." The hot-process treatment is more effective since it extends the principles and reactions of cold-process softening to higher temperatures which permit much greater hardness reduction and simultaneously result in deaeration, flashing off of dissolved carbon dioxide, and removal of carbonate hardness without the use of chemicals (by conversion of soluble calcium bicarbonate to insoluble calcium carbonate which can be filtered from the water). The chemical treatments used in both the cold and hot water processes are basically the same and involve treatment with hydrated lime (calcium hydroxide or $Ca(OH)_2$) followed by treatment with soda (sodium carbonate or Na_2CO_3).

Some of the materials ordinarily present in hard water may not be contributory to the hardness of the water, but they nevertheless will react with the lime. These substances include carbon dioxide and sodium bicarbonate as shown in the equations below. In order to simplify the presentation of the reactions that occur during the chemical treatment of water, the equations are given below in sequence. However, it should be kept in mind that the actual chemical conversions take place simultaneously.

In the cold process, the addition of lime to the water causes a reaction with dissolved carbon dioxide according to the following chemical equation:

Equation 1

$$\begin{array}{llll} 2CO_2 & + \; Ca(OH)_2 & \rightarrow & Ca(HCO_3)_2 \\ \text{Carbon dioxide} & \text{Calcium hydroxide} & & \text{Calcium} \\ & \text{(hydrated lime)} & & \text{bicarbonate} \end{array}$$

This first reaction produces calcium bicarbonate, thus adding to the carbonate hardness of the water.

The reaction shown in equation 1 does not occur in the hot-process since as mentioned above, dissolved carbon dioxide flashes off when the heat is applied.

The next reaction that occurs with lime treatment is the conversion of the soluble calcium bicarbonate to the insoluble carbonate salt as shown below:

Equation 2

$$\begin{array}{llllll} Ca(HCO_3)_2 & + \; Ca(OH)_2 & \rightarrow & 2CaCO_3 & + & 2H_2O \\ \text{Calcium} & \text{Calcium hydroxide} & & \text{Calcium} & & \text{Water} \\ \text{bicarbonate} & \text{(hydrated lime)} & & \text{Carbonate} & & \\ & & & \text{(insoluble)} & & \end{array}$$

The calcium carbonate which precipitates from the water can be removed by filtration or settling.

Partial softening is sometimes accomplished in water treatment plants by the addition of less than the full amount of lime required for complete conversion to calcium carbonate.

The lime consumption is increased by the presence of magnesium or sodium bicarbonates as follows:

Equation 3

$Mg(HCO_3)_2$	$+ Ca(OH)_2$	$\rightarrow MgCO_3$	$+ CaCO_3$	$+ 2H_2O$
Magnesium bicarbonate	Calcium hydroxide (hydrated lime)	Magnesium carbonate (soluble)	Calcium carbonate (insoluble)	Water

Equation 4

$2NaHCO_3$	$+ Ca(OH)_2$	$\rightarrow Na_2CO_3$	$+ CaCO_3$	$+ 2H_2O$
Sodium bicarbonate	Calcium hydroxide (hydrated lime)	Sodium carbonate (soluble)	Calcium carbonate (insoluble)	Water

Since the magnesium carbonate is soluble, the additional lime that is used for the reaction in equation 3 does not remove any further hardness. The sodium bicarbonate that may be present does not contribute to water hardness hence the lime used in its conversion to sodium carbonate is in a sense "wasted."

The soluble magnesium carbonate formed by the reaction shown in equation 3 and the soluble sulfate and chloride of magnesium that may be present in the water react with further quantities of lime as shown in the following equations:

Equation 5

$MgCO_3$	$+ Ca(OH)_2$	$\rightarrow Mg(OH)_2$	$+ CaCO_3$
Magnesium carbonate	Calcium hydroxide (hydrated lime)	Magnesium hydroxide (insoluble)	Calcium carbonate (insoluble)

Equation 6

$MgSO_4$	$+ Ca(OH)_2$	$\rightarrow Mg(OH)_2$	$+ CaSO_4$
Magnesium sulfate	Calcium hydroxide (hydrated lime)	Magnesium hydroxide (insoluble)	Calcium sulfate (soluble at the concentrations found in water)

Equation 7

$MgCl_2$	$+ Ca(OH)_2$	$\rightarrow Mg(OH)_2$	$+ CaCl_2$
Magnesium chloride	Calcium hydroxide (hydrated lime)	Magnesium hydroxide (insoluble)	Calcium chloride

The insoluble calcium carbonate and magnesium hydroxide salts produced in the above reactions are removed from the water as a sludge by settling or by filtration. The soluble calcium sulfate and calcium chloride produced in equations 6 and 7, respectively, as well as the naturally occurring chloride and sulfate of calcium contribute to water hardness. These soluble calcium salts can be removed by the second main step of the chemical softening process; i.e., by treatment with soda. The chemical reactions that occur are as follows:

Equation 8

$CaSO_4 \; +$	$Na_2CO_3 \; \rightarrow$	$CaCO_3 \; +$	Na_2SO_4
Calcium	Sodium	Calcium	Sodium
sulfate	carbonate	carbonate	sulfate
	(soda)	(insoluble)	

Equation 9

$CaCl_2 \; +$	$Na_2CO_3 \; \rightarrow$	$CaCO_3 \; +$	$2NaCl$
Calcium	Sodium	Calcium	Sodium
chloride	carbonate	carbonate	chloride
	(soda)	(insoluble)	

Thus, as shown in the above equations, there are four fundamental processes requiring the use of lime and soda to remove the calcium and magnesium salts from water to lower the water hardness. As mentioned earlier, for the common municipal and industrial purposes, the hardness of water is reduced but not usually completely eliminated.

The second common method of water softening, ion exchange, is based on the removal of calcium and magnesium ions from water by replacement with sodium or hydrogen ions. The two processes involved are called *sodium zeolite* softening and *hydrogen zeolite* softening.

In the first process, the hard water is passed through a bed of sodium zeolite (either natural materials consisting principally of sodium-aluminum silicate or synthetic materials of a carbonaceous nature). The sodium zeolite is capable of replacing the calcium or magnesium from their salts of bicarbonates, sulfates, chlorides, etc., with sodium. The calcium or magnesium remain in the bed as the zeolite salts. The fundamental equations are as follows:

Equation 10

$Na_2Z \; +$	$CaX_2 \; \rightarrow$	$CaZ \; +$	$2NaX$
Sodium	Calcium	Calcium	Sodium
zeolite	salt	zeolite	salt
			(soluble)

Equation 11

Na_2Z	$+ MgX_2$	$\rightarrow MgZ$	$+ 2NaX$
Sodium zeolite	Magnesium salt	Magnesium zeolite	Sodium salt (soluble)

The zeolite bed, as is evident from the above equations, has to be regenerated before it is completely converted to calcium and magnesium zeolite if it is to continue to operate effectively as a water softener. This is accomplished by passing a strong sodium chloride solution through the bed. The reverse of the reactions shown in equations 10 and 11 above take place; calcium and magnesium zeolites are changed to sodium zeolite, and the bed is regenerated and is again capable of softening water.

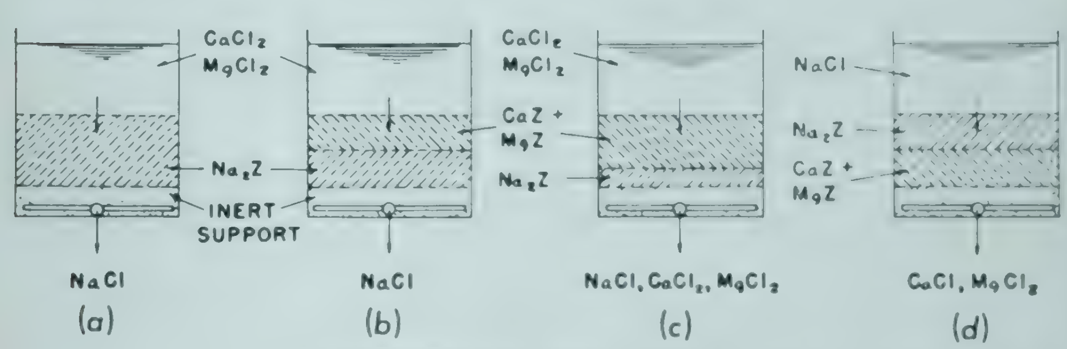


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FIG. 27. DIAGRAMMATIC SKETCH SHOWING CHANGES IN ZEOLITE BED DURING SOFTENING AND REGENERATION

The sodium zeolite process is illustrated in Fig. 27 (Powell 1954). At (*a*), the calcium and magnesium salts (the chloride salts are used for purposes of illustration) are converted to sodium chloride after passage through the sodium zeolite. At (*b*) and later at (*c*), the sodium is progressively being replaced by calcium and magnesium until regeneration is necessary. This is shown at (*d*) where the added sodium chloride solution replaces the calcium and magnesium which are washed from the bed as calcium and magnesium chlorides. When the regeneration is completed, the bed is substantially in the same condition as at (*a*) and is again capable of water softening.

The same principle of water softening applies with *hydrogen zeolite* softening with the exception that the calcium and magnesium ions present in hard water are replaced by hydrogen rather than sodium as shown in the following chemical equations:

Equation 12

$$\begin{array}{llll} H_2Z & + \; CaX_2 & \rightarrow \; CaZ & + \; 2HX \\ \text{Hydrogen} & \text{Calcium} & \text{Calcium} & \text{Acid} \\ \text{zeolite} & \text{salt} & \text{zeolite} & \text{(soluble)} \end{array}$$

Equation 13

$$\begin{array}{llll} H_2Z & + \; MgX_2 & \rightarrow \; MgZ & + \; 2HX \\ \text{Hydrogen} & \text{Magnesium} & \text{Magnesium} & \text{Acid} \\ \text{zeolite} & \text{salt} & \text{zeolite} & \text{(soluble)} \end{array}$$

With calcium and magnesium bicarbonates, the acid formed is carbonic acid (H_2CO_3) which breaks up on aeration to carbon dioxide and water. The carbon dioxide is thus removed from the water. In waters containing other calcium and magnesium salts, such as sulfates, chlorides, etc., the corresponding mineral acids; sulfuric acid, hydrochloric acid, etc., are formed and may require alkali neutralization.

The hydrogen zeolite bed is regenerated by passing an acid through it; sulfuric acid being commonly used.

The water treatment techniques described above are the ones that are in common usage. In addition, there are several processes that are employed when the raw water may have some unusual contaminants or when water of a high purity is required for special purposes. These latter conditions are less frequently met in bakeries, therefore the specialized treatments will not be covered in this chapter. For a description of the further treatments as well as for more details on the common water treatments employed, the reader is referred to standard texts on water conditioning such as the Handbook prepared by Betz and Betz (1945) and Powell's "Water Conditioning for Industry" (1954).

Bakers who are interested in the type and composition of the water in their plants can obtain the services of local government agencies or consulting laboratories. The common types of tests that can be used to evaluate water are described in a later section of this chapter.

WATER IN BAKING

It is obvious to every baker that water is an essential dough ingredient. It is necessary to add water to doughs to form the gluten which is the matrix of bread doughs. Water is also necessary in the starch swelling process and to bring the dough ingredients into intimate contact with each other so that the complex reactions of bread-making can take place.

Besides the water that is normally added to the other dough ingredients, small amounts are also added along with the yeast, flour, milk solids, etc., none of which are dry in the strict sense, but which contain water that will eventually become part of the dough.

The water that is added to the other ingredients to form a dough is generally called the *absorption* by bakers and in most doughs has to be carefully and rigidly set so as to secure optimum dough characteristics for proper and easy handling as well as for the best quality bread obtainable.

Since the amount of water that is added to bread doughs represents a large proportion of the dough, the small quantities of active ingredients that are present in the water supply can have distinct effects on dough properties.

In general, water of a medium hardness (i.e., from about 50 to 100 p.p.m.) with a neutral or slightly acidic pH is preferred for baking uses.

Excessively alkaline waters can adversely affect dough fermentation by raising the pH of the doughs to a point above the optimum (pH 4 to 5) at which the yeast and flour enzymes function. In addition rope and mold inhibitors do not function as well under alkaline conditions. The use of acidifying agents (acetic acid, lactic acid) or acidic dough improvers can be used to overcome the effects of excessively alkaline water.

Water that is too soft can result in sticky doughs because of the absence of gluten tightening minerals. However, this condition is rarely encountered in bakeries because of the widespread use of dough improvers and yeast foods which supply the bulk of the necessary minerals.

Water that is too hard may retard fermentation to a certain extent by toughening the gluten. This adverse affect can be corrected by modifying the water supply or by increasing the yeast levels and decreasing dough improver levels.

Each of the generalities mentioned above are covered in more detail below.

pH of Water

Although doughs have considerable buffering capacity by virtue of their protein components (from flour, milk solids, etc.) the use of excessively alkaline water may require the addition of acidifying agents such as vinegar, lactic acid, or monocalcium phosphate (found in some dough improvers).

If the water used is alkaline enough to raise the dough pH, a deleterious effect on the yeast and flour enzymes might become noticeable (Haas 1927). These enzymes function best at dough pH's between about 4 to 5. For example, Howe and Glick (1945) have demonstrated that wheat proteases (which help overcome dough buckiness) have pH optima of 4.5 or 5.0 depending on their source. It has also been reported by Wayt (1936) that because of the slower rate of enzymatic reactions in doughs made with alkaline waters, sponge times may have to be extended by 1 to 1½ hours. This condition can be corrected by the addition of monocalcium phosphate.

In addition to affecting enzymatic reactions, the use of excessively alkaline water may result in higher than normal requirements for oxidizing agents, such as potassium bromate. Hlynka and Chanin (1957) demonstrated that as dough pH's are raised, the bromate requirements are increased. For example, they showed that dough with an initial pH of 7.0 required 20 p.p.m. of potassium bromate for optimum loaf volume, whereas a dough with an initial pH of 5.3 required only 5 p.p.m. of potassium bromate for optimum loaf volume.

Another factor that should be considered when alkaline water is used in bakeries is its effect on the usual mold or rope inhibitors that are added to bread doughs. It is well known that these substances; e.g., vinegar, monocalcium phosphate, sodium diacetate, and sodium propionate function best under slightly acidic conditions, particularly against rope. Water that is excessively alkaline can counteract the effect of these inhibitors and increase the levels required in doughs. It was pointed out by Glabe (1950) using data from the Hearings on the Federal Standards of Identity for Bread that water constituents varied significantly at different points in the United States with the result that the requirements for mold and rope inhibitors also varied. These variations are shown in Table 33. Using Sioux City as an example of an extreme case, 60 lbs. of water per 100 lbs. of flour would neutralize 25 per cent of the permissible upper level of vinegar, or all of the presently allowable limit of the monocalcium phosphate. However, this situation may not be as extreme as appears from these figures, since the data are based on adjustment of the pH of the water alone and do not take into account the buffering capacity of other dough ingredients, such as flour or milk solids.

The same data shown in Table 33 also illustrate the extreme variations that can occur in water supplies from different cities.

TABLE 33

QUANTITIES OF VINEGAR OR OF MONOCALCIUM PHOSPHATE REQUIRED TO BRING 60 POUNDS OF WATER TO pH OF 5.0

Source of Water	50 Grain Vinegar, Ounces	Monocalcium Phosphate, Ounces
Little Rock, Arkansas	0.3	1.1
Kansas City, Missouri	0.8	1.8
Minneapolis, Minnesota	1.4	2.7
Chicago, Illinois	2.5	4.6
Sioux City, Iowa	8.3	5.2

Water Contaminants

Not all of the common mineral components of water are believed to have an effect on doughs or on fermentation. Thus, it was pointed out by M. M. Brooke (1939) that the following materials in the quantities and forms found in natural water have no effect on fermentation: copper salts, iron salts, aluminum salts, tannic acid, silicates, and phosphates. However, evidences of probable effects of the following salts were found: calcium oxide, calcium carbonate, calcium sulfate, magnesium chloride, magnesium oxide, and sodium bicarbonate. The reader will note that all of the above salts, with the exception of sodium bicarbonate, contain calcium or magnesium ions that contribute to water hardness.

The range of concentrations of four of the above salts in water from leading industrial centers was reported by C. L. Brooke (1939) to be as follows: calcium carbonate, 8 to 230 p.p.m.; calcium sulfate, 10 to 300 p.p.m.; magnesium chloride, 2 to 100 p.p.m.; and sodium bicarbonate, 4 to 250 p.p.m. The amounts of magnesium oxide and calcium oxide in natural water were claimed to be low.

Brown (1939) systematically studied the six mineral salts mentioned above for their effects on fermentation and dough quality. He added these salts to distilled water in concentrations ranging from 50 to 1,000 p.p.m. and used the "synthetic water" in straight and sponge-doughs made without added dough improvers. Control doughs, containing distilled water were used as reference points. He found that sodium bicarbonate at levels ranging from 100 to 1,000 p.p.m. did not affect dough fermentation or loaf volumes. Magnesium oxide at levels ranging from 50 to 500 p.p.m. did not affect sponge doughs but at a level of 500 p.p.m. in straight doughs, bread volume was decreased. The three salts, magnesium chloride at levels from 50 to 500 p.p.m., calcium carbonate at levels from 100 to 1,000 p.p.m., and calcium sulfate at levels from 50 to 300 p.p.m. were found to be beneficial to fermentation and to give improved loaf volumes. Water containing calcium hydroxide, on the other hand, at concentrations of 100, 500, and 1,000 p.p.m. was found to have increasingly deleterious effects on fermentation and loaf volumes when the yeast was emulsified in the water according to normal bakery procedures. This effect is due to the alkalinity of the calcium hydroxide water and was overcome when the yeast was crumbled into the mixer on top of the flour and mixed into the dough without preliminary mixing with the alkaline water. The buffering capacity of the flour in overcoming the alkalinity of the water was sufficient to protect the yeast. This same adverse effect was found to a much lesser degree with magnesium oxide, as was expected, because of the much lower solubility of magnesium oxide compared to calcium hydroxide. Although Brown used distilled water for his control doughs, he did test the effect of city water (without additives) and $^1/_4$ per cent yeast food with distilled water. He found that the use of yeast food resulted in the largest bread volumes in the complete test series, followed by the use of city water. In all cases in which magnesium and calcium salts were used, stiffer doughs resulted pointing to a strengthening effect of these salts on gluten. The alkali chlorides and sulfates, particularly calcium sulfate, were also recognized by Haas (1927) as being beneficial to doughs by virtue of their gluten strengthening properties.

Loving (1939) investigated the effect of mixtures of salts at several concentrations using five different commercial brands of yeast. He used pressuremeter measurements, fermentation times and loaf quality as criteria. The data indicate that different yeasts displayed varying responses to the effects of the salts tested, particularly with the alkaline calcium hydroxide. Some of the yeasts were remarkably tolerant to high levels of calcium hydroxide (1,000 p.p.m.) pointing out that with highly alkaline waters the baker's choice of yeast is an important consideration.

Juvrud (1939) studied the effects of sodium bicarbonate, magnesium chloride, calcium carbonate, calcium hydroxide, and calcium sulfate alone and in combination with dough improvers, on gassing power and straight dough fermentation and bread quality. He found marked increases in gassing power when the mineral salts were supplemented with dough improvers, particularly in the case of calcium hydroxide. The latter is probably due to the acidic character of the dough improvers in overcoming the alkalinity of the calcium hydroxide. In the baking tests, the dough improvers also resulted in improvements beyond those of the mineral salts alone. In interpreting Juvrud's findings it should be kept in mind that some of the components of the dough improvers have effects on doughs that are distinctly different from the mineral salts tested. It would be expected that the ammonium salts and oxidizing salts, normally present in dough improvers will improve gassing power and bread scores thus affording a practical means to the baker of overcoming the deleterious effects of excessively hard or highly alkaline waters.

It was indicated by Haas (1927) that fortunately few salts in water normally occur in sufficient quantity to exert a pronounced effect on dough fermentation. He mentioned hydrogen sulfide as a water contaminant that has a powerfully detrimental effect in very small quantity and suggested that water containing this substance should not be used in bread doughs.

As mentioned previously, it is generally agreed that chlorine and fluoride are without any effect on bread doughs (Kirk 1951, and Dunn 1941).

Cryns (1936), on the other hand, pointed out that it was his experience that the use of chlorinated water shortens fermentation time to a certain extent and improves bread quality, particularly if lower grade or weaker flours are used.

Although chlorine is added to water at water treatment plants to kill bacteria and other micro-organisms, it should be kept in mind that water pollution can occur at distribution points after the water treatment is completed. For example, pollution of the water supply can occur within bakeries due to poorly assembled water fixtures or defective plumbing. Readey (1952) has pointed out that faucets that are submerged in a filled sink or in cooking vessels can result in back-siphonage of the contents of the sink or cooking vessel with the result that drinking fountains or other outlets might deliver contaminated water. In addition, water closets that are flooded because of stoppages in the waste lines can back-siphon contaminated water to other outlets. Defective or leaky sewage pipes might allow drippage of sewage on food products. These conditions leading to pollution of the bakery water supply or food products should also be considered and corrected when they are present.

The consequences of using water of different composition and the practical means of overcoming possible deleterious effects have been reviewed by Pickering (1936). The rate of fermentation is generally decreased when alkaline waters are used. This situation can be corrected by the use of longer fermentation times, by using more yeast, or by adding acidifying agents such as vinegar, lactic acid, or acid-type dough improvers. With alkaline waters, normal absorptions can be used and if one of the above corrective measures is applied, good quality bread can be obtained.

Soft waters result in sticky doughs which require less than the normal amount of absorption. The deficiencies of soft water can easily be corrected by an increase in the use of dough improvers and dough salt. The lower pH that normally occurs with soft waters has a tendency to favor fermentation and may necessitate the use of shorter dough fermentation periods.

Hard waters have a tendency to toughen the gluten and result in "buckiness." Increased yeast quantities will alleviate this condition by affording more vigorous fermentation thus softening the dough somewhat. Other corrective measures include lower dough improver levels and increased diastatic malt levels.

A similar summary was prepared by Kirk (1951) in tabular form as shown in Table 34. It should be noted that the hardness classification used by Kirk is slightly different than that shown in Table 32 on p. 78 of this chapter.

Table 34

RELATIONSHIP OF WATER CHARACTERISTICS TO YEAST FOOD REQUIREMENTS[1]

Type of Water	Sub-class of Water	Type of Yeast Food Needed	Amount of Yeast Food Needed	Other Special Treatment
I. Acid (Below 7 pH)	A. Soft (less than 120 p.p.m.)	Regular	Normal	Salt in sponge (plus calcium sulphate in extreme cases)
	B. Moderately hard (120–180 p.p.m.)	Regular	Normal	None
	C. Hard (more than 180 p.p.m.)	Regular	Less than normal	Malt in sponge (in extreme cases)
II. Average (7 to 8 pH)	A. Soft	Regular	More than normal	None
	B. Moderately hard	Regular	Normal	None
	C. Hard	Regular	Less than normal	Malt in sponge
III. Alkaline (Above 8 pH)	A. Soft	Acid or regular plus calcium acid phosphate	More than normal	Calcium acid phosphate (in extreme cases)
	B. Moderately hard	Acid	Normal	None
	C. Hard	Acid	Less than normal	Much malt (plus vinegar or lactic acid in extreme cases)

[1] From Kirk (1951).

Skovholt (1948) has pointed out that the contributions of dough improvers far exceed the normally encountered concentrations of mineral salts commonly occurring in natural waters. The usual level of common dough improvers for example, will contribute several times (1,000 p.p.m.) as much calcium sulfate as found in normal waters. In order to explain why waters differing by 100 to 200 p.p.m. in hardness have significant effects on dough properties, he suggests that the trace elements found in water might play a more important part than ordinarily considered. This possibility is supported by an earlier finding that only a fractional part per million of an element like vanadium would have to be present in the water used in baking to decidedly modify dough characteristics. Effects due to trace elements are likely and need to be considered in further investigations on the quality of water used in baking.

TESTING THE WATER SUPPLY

If problems in a bakery are suspected to be due to the water supply either from the standpoint of dough effects as covered earlier in this chapter or because of scale deposits or corrosive effects on pipes, valves, meters, boilers, etc., there are several common tests that can be performed on the water to determine the corrective measures that should be applied. These tests can be performed in the bakery if the necessary facilities are available or water samples can be tested at local testing laboratories.

The frequency of the water testing schedule and the types of tests to be applied depend on the source of the water, the expected seasonal fluctuations, the variation in rainfall, the proximity of the water supply to tidal waters, and many other factors. In general, surface waters can be expected to show larger fluctuations in composition than underground waters; municipal water supplies are probably less variable than private water supplies. In areas with municipal water supplies information about the composition of the water and the expected variations can usually be obtained from the local water supply organizations.

In preparing for analytical evaluations of the bakery water supply, prime consideration should be given to proper sampling. Samples should be taken from representative areas throughout the bakery and as close as possible to or actually at the outlet points at which the water will be used.

The samples should generally be collected in well washed and rinsed resistant glass containers, such as Pyrex glass. If several tests are to be made, a sample size of 500 to 1,000 ml. should be adequate.

Before samples are taken from an infrequently used outlet, the line should be thoroughly flushed to remove all stagnant water and any sediment that may have accumulated.

Containers that are to be used for collecting water samples for bacteriological assays must be sterilized and properly stoppered to prevent bacterial contamination from sources other than the water sample to be tested.

The main tests of interest to bakers include (1) alkalinity, (2) pH, and (3) hardness. These tests will be described in detail below. There are several other tests which may be of interest to bakers who have specific equipment problems (i.e., scale deposits or corrosive effects). These may include tests for (1) sulfate ion, since calcium sulfate scale is frequently encountered in boilers, (2) soluble silicates which form extremely hard scale but have no perceptible influence on dough properties or fermentation, (3) iron which can discolor equipment, (4) manganese which may sometimes deposit as black manganese hydroxide and thus clog pipes and valves or discolor equipment, and (5) dissolved gases such as oxygen, carbon dioxide and hydrogen sulfide which render water highly corrosive and can cause severe damage to pipes, valves, water jackets, water meters, boilers, etc. Test procedures for these possible water contaminants have been covered by Powell (1954).

In addition to the above tests there are several standard tests for common microbial contaminants. These tests are generally carried out by the Official Procedures of the American Public Health Association (Anon. 1936) and are used to determine the possible presence of harmful microorganisms that might result from pollution of the water supply.

The procedures that have been adopted for the common tests which are of most significance to bakers are as follows:

Alkalinity Determination

A total alkalinity test, employing methyl orange as an indicator is generally employed. It is a measure of the alkalinity due to the more strongly alkaline hydroxides, carbonates, phosphates, and silicates, as well as the less alkaline bicarbonates and phosphates.

Samples containing insoluble material should be filtered before the test is started. In this procedure, 100 ml. samples are used. The alkalinity results are expressed as equivalent calcium carbonate.

Reagents.—*Methyl orange indicator solution,* prepared by dissolving 1 gram of methyl orange in 1 liter of distilled water; and *standard sulfuric acid, 0.02 N.*

Procedure.—To a measured 100 ml. of clear sample in an Erlenmeyer flask over a white background, add methyl orange indicator until a distinct yellow color is produced. Titrate the sample with the 0.02 *N* sulfuric acid solution from a burette having graduation marks for each 0.1 ml. The acid should be added slowly and the sample swirled or stirred until a definite pink tinge is seen in the yellow color of the sample. A strong pink color indicates overtitration of the end point. In case of difficulty in observing the end point add a second sample containing the same amount of indicator to a second flask and place this next to the sample being titrated. By comparison, the first definite change in color can be seen.

Calculation.—Read from the burette the total volume of acid which has been used.

$$\text{p.p.m. alkali, as CaCO}_3 = \frac{\text{ml. acid} \times 1{,}000}{\text{ml. sample}}$$

Example: If a 100 ml. sample of water is used and 7 ml. of acid is required, the alkalinity is

$$\text{Alk.} = \frac{7 \times 1{,}000}{100} = 70 \text{ p.p.m.}$$

Water pH

The pH value is defined as the logarithm of the reciprocal of the gram equivalents per liter of the hydrogen ion. It may be expressed as follows:

$$\text{pH} = \log \frac{1}{(\text{H}^+)}$$

where (H^+) is the hydrogen ion concentration in moles per liter.

The pH value of water solutions is a number between 0 and 14 and represents the acidity or alkalinity of the solution. When the pH is 7, the water is said to be neutral. When the pH is below 7, the solution is said to be acid. The lower the pH, the more acid is the solution. Conversely, when the pH is above 7, the solution is alkaline. The higher the pH, the higher is the alkalinity.

For the accurate determination of pH, the electrometric method, using glass and calomel electrodes and a potentiometer, is employed. These units are available as "pH meters" and are calibrated to read directly in terms of pH. The current necessary for the operation of a pH meter is obtained either from electrical lines or batteries.

Color-comparator methods, using either paper impregnated with indicators or a water solution of indicators can be used for less accurate, but under some conditions, adequate pH measurements. The indicators turn different colors at different pH's and by comparing the color resulting from contact with the water sample being tested with fixed color standards supplied with the color comparator kit, the pH of the water sample can be determined.

Total Water Hardness

The determination of total water hardness by titration with standard soap solution is used in the analysis of raw-water supplies. It is based on the ability of the soap solution used for titration to form calcium and magnesium soaps which do not form a stable lather on shaking. When an excess of soap solution has been added, a stable lather will be formed.

Reagents:

Phenolphthalein Indicator Solution.—Dissolve 5 grams of phenolphthalein in 1 liter of a 50 per cent solution of ethyl alcohol in distilled water. Neutralize with dilute NaOH solution to a faint pink color.

Sodium Hydroxide Solution, 0.1 N (Carbonate Free).—Store in a 1-oz. dropping bottle.

Sulfuric Acid Solution, 0.1 N.—Store in a 1-oz. dropping bottle.

Standard Hard Water.—A calcium chloride standard solution may be used for the standard hard water. However, if magnesium is suspected of being present in the water sample, the accuracy of the test may be improved by mixing the calcium standard solution with the magnesium sulfate standard solution in the ratio of calcium to magnesium in the sample. For average water, a mixture of 80 ml. of standard calcium chloride and 20 ml. of standard magnesium sulfate can be used.

Calcium Chloride Standard Solution.—Dissolve 0.5 gram of pure calcium carbonate in a beaker with a little dilute hydrochloric acid. Wash down the sides of the beaker with freshly boiled and cooled distilled water. Neutralize the excess acid with ammonium hydroxide using litmus paper or phenolphthalein as the indicator. Make up to 500 ml. with freshly boiled and cooled distilled water, and store in a tightly stoppered glass bottle. One milliliter equals 1 mg. of hardness, as calcium carbonate.

Magnesium Sulfate Standard Solution.—Dissolve 0.6 gram of anhydrous magnesium sulfate in 500 ml. of freshly boiled and cooled distilled water. Store in a tightly stoppered Pyrex glass bottle. One milliliter equals 1 mg. of hardness, as calcium carbonate.

Standard Soap Solution.—Dissolve approximately 100 gm. of pure powdered castile soap in 1 liter of 80 per cent ethyl alcohol. Let this solution stand at least overnight, then decant. This is the stock solution and is about 9 to 10 times more concentrated than the standard solution. Dilute a portion of the stock solution with 80 per cent ethyl alcohol until, when an aliquot is titrated against calcium chloride solution (by procedure given below), 1 ml. of the resulting dilution is equivalent to 1 ml. of the standard calcium chloride solution. The adjustment of the strength of the dilution should include an allowance for the lather factor (described below) of the adjusted soap solution from at least five determinations. One milliliter of standard soap solution — lather factor = 1 mg. $CaCO_3$.

Lather Factor.—The lather factor of the soap solution is determined by adding small increments of soap solution to 50 ml. of freshly boiled and cooled distilled water until a stable lather is formed after shaking. Since the soap solution may change, the lather factor should be checked at least once a week.

Add 50 ml. of the distilled water to the 8-oz. test bottle and adjust the pH value to the phenolphthalein end point as described below. Titrate with the soap solution until a permanent lather is formed. Record the milliliters of soap used as the lather factor.

Procedure.—In order to obtain reproducible results, the sample should be brought to the pH of the phenolphthalein end-point (about 8.3). The temperature of the samples should be between 60° and 100°F. Any suspended matter should be removed by filtration.

Add 50 ml. of the sample to be tested to a clean 8 oz. glass bottle, fitted with a glass or rubber stopper. Add three drops of phenolphthalein indicator and adjust the pH value to the end-point with either 0.1 *N* sodium hydroxide or 0.1 *N* sulfuric acid as required.

To the neutralized sample, add standard soap solution from a burette in small increments of 0.2 ml. at a time and shake the bottle vigorously after each addition. When a permanent lather begins to form, reduce the increments of soap solution to 0.1 ml. until, with further shaking, a lather will persist over the surface of the water for a period of 5 min. while the bottle is lying on its side. Record the milliliters of soap solution used.

When this point is reached, test for a false end-point by adding 0.2 ml. more of the soap solution, and shake the bottle. If the lather disappears, the titration should be continued to a final end-point. The presence of magnesium in the sample may be the cause of the false end-point.

Calculation

$$\text{Total hardness, as p.p.m. } CaCO_3 = (\text{ml. soap solution} - \text{ml. lather factor}) \times \text{hardness factor}$$

Example.—If 50 ml. of sample requires 1.5 ml. of soap solution to produce a stable lather, the lather factor is 0.2 ml., and the hardness factor is 20, then $20 \times (1.5-0.2) = 20 \times 1.3 = 26$ p.p.m. total hardness, as $CaCO_3$.

Hardness Factor.—The factor used for calculating the hardness should be determined at least once a week since the soap solution may change.

This test is made by adding 5 ml. of standard hard water to 45 ml. of distilled water. The pH adjusted and a soap solution titration is made as above.

Calculation

$$\text{Hardness factor} = \frac{5 \times 20}{(\text{ml. of soap} - \text{ml. lather factor})}$$

Example.—If 5 ml. of the standard hard water requires 4.1 ml. of soap solution and the lather factor is 0.2 ml., then the soap solution consumed is $4.1 - 0.2 = 3.9$ ml. This is equivalent to the 5 mg. of calcium carbonate in the 5 ml. of standard water used. Therefore the hardness factor may be calculated as

$$20 \times \frac{5}{3.9\ (\text{ml. of soap used})} = 25.6$$

The above test methods or the other analytical procedures mentioned above can be used when the bakery water supply is suspected to be the cause of deficiencies in fermentation or general dough and bread characteristics. If the water supply is found to be the cause of these deficiencies, the application of the proper corrective measures described earlier in this chapter should adequately solve the problems.

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CHAPTER 4

R. W. Mykleby

Milk and Milk Derivatives

Fluid milk as such, was undoubtedly the first form of milk used in the baking of bread by the housewife. With the evolution that science and technology have fostered, the household baking operation has given way to the small retail bake shop, the wholesale bakery, and finally the still larger multi-plant bakery chains covering large geographic areas of the country. Indeed the recent emphasis on continuous processing with its potential labor economies has made its impact on all of the baking industry. Further, the increasing variety of bakery products, such as dry mixes, refrigerated and frozen baked goods, brown and serve, etc., has created a need for raw materials processed to meet the specific needs of these varied elements of the baking industry.

Milk products, and particularly nonfat dry milk, have become a rather widely used ingredient of baked goods. Nonfat dry milk levels in breads, for example, can vary from zero per cent to as high as 25 per cent (see p. 111). The nonfat dry milk levels in cakes can vary from 0 to 10 or 12 per cent (see p. 113). Milk solids levels in many other specialty forms of baked products and prepared mixes will typically vary between 5 and 10 per cent—all based on flour weight.

Figures compiled by the American Dry Milk Institute show the United States utilization of dry milks in 1958 to be as follows:

	Bakery	Prepared Dry Mixes
Nonfat milk	272,500,000 lbs.	40,600,000 lbs.
Dry whole milk	8,000,000 lbs.	. . .
Dry buttermilk	37,200,000 lbs.	8,400,000 lbs.

While end use figures are not available for fluids and concentrates, it is an accepted fact that dry milk products account for the greatest milk equivalent disposition in the baking industry.

With these developments and this varied usage, it is imperative that milk always be produced and processed by techniques that will result in dairy products meeting specific performance specifications as bakery raw materials. It is the purpose of this chapter to discuss the subject of milk and milk derivatives in terms of the technology involved, the commercial products now available, and the methods which can be

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used for evaluating milk products for their specific performance in the bakery industry.

TECHNOLOGY OF MILK IN RELATION TO BAKING

The Individual Milk Constituents

Milk is generally defined as the whole, fresh, lacteal secretion obtained by the complete milking of one or more healthy cows, which contains not less than 8.25 per cent milk solids not fat and not less than 3.25 per cent milk fat, excluding that obtained within 15 days before and five days after calving, or such longer period as may be necessary to render the milk practically colostrom free. As is clear from this definition, the term "milk" unqualified means cows' milk. All other milk is qualified by some adjective as goats' milk, pigs' milk, human milk, etc.

The individual constituents of milk can be listed very simply as butterfat, milk protein, lactose, ash, and water. A typical analysis of milk will show it to contain:

TYPICAL ANALYSIS OF MILK

Milk Constituent	Per cent
Butterfat	3.9
Protein	3.5
Lactose	4.9
Ash	.7
Water	87.0
Total	100.0

The dairy industry has employed such processes as separation, churning, evaporation, drying, and precipitation to segregate all or portions of these milk constituents. The specific method or methods employed in manufacturing dairy products will, in turn, determine the chemical composition of the end product, and, in many instances, will also determine its performance characteristics in a baking operation.

Milk Fat.—Commercially referred to as butterfat, is essentially a triglyceride consisting of the glycerol molecule united with three parts or moles of fatty acids. There have been at least 29 different fatty acids isolated from butterfat. It is the proportion of these various mixed fatty acid components of butterfat that gives butterfat its individual physical characteristics.

Table 35 shows the percentage range of the more important fatty acids found in milk fat and their respective melting points. From this it is apparent that considerable variation exists in the fatty acid composition of milk fat. These variations are due to such factors as the breed of cattle, individuality of the cow, period of lactation, and type of feed used. The type of feed given cattle is of considerably greater practical significance than the other factors. Consequently, milk fat produced under different climatic conditions, during different seasons of the year, and in different sections of the country can exhibit somewhat different physical and chemical characteristics.

TABLE 35

FATTY ACIDS IN BUTTERFAT

Acid	Carbon Atoms	Formula	Melting Point[1] Degrees F.	Percentage[1] Range
Saturated				
Butyric	4	C_3H_7COOH	17.6	2.2 to 5.5
Caproic	6	$C_5H_{11}COOH$	14.9	1.3 to 3.3
Caprylic	8	$C_7H_{15}COOH$	61.1	0.5 to 1.9
Capric	10	$C_9H_{19}COOH$	87.8	0.3 to 3.0
Lauric	12	$C_{11}H_{23}COOH$	118.4	2.6 to 7.7
Myristic	14	$C_{13}H_{27}COOH$	136.4	9.9 to 22.6
Palmitic	16	$C_{15}H_{31}COOH$	147.2	5.8 to 38.6
Stearic	18	$C_{17}H_{35}COOH$	158.2	1.8 to 20.4
Unsaturated				
Oleic	18	$C_{17}H_{33}COOH$	57.2	25.3 to 48.3
Linoleic	18	$C_{17}H_{31}COOH$	−0.6	0.0 to 5.4

[1] Hunziker (1940).

As compared to most other food fats, milk fat contains relatively large quantities of the saturated fats and relatively small quantities of the unsaturated fats. Because of this, milk fat is more stable toward heat than a fat containing a large proportion of unsaturated glycerides. Table 36 gives the fatty acid analyses of some other fats of animal and plant origin.

Milk fat, when used in baking, serves much the same purpose as other fats; namely, that it lubricates and weakens the gluten structure to shorten and tenderize the product. Further, milk fat contains some of the desirable carbonyl compounds such as diacetyl, which contribute to the characteristic "butter flavor" traditionally associated with butterfat (Kummerow 1957).

Butterfat contains small quantities of materials which may be referred to as minor constituents of butterfat. The phospholipids, lecithin and cephalin, are not true fats, but are fat-like in nature. The phospholipid content of milk varies from 0.025 to 0.040 per cent and the lecithin content from 0.012 to 0.018 per cent. In the separation of cream and churning of butter, much of the lecithin content finds its way into the buttermilk portion, giving buttermilk a relatively high lecithin content. The lecithin content of the fat in buttermilk will consequently range between 1.90 and 5.85 per cent. The lecithin content of the fat of churned butterfat, on the other hand, will normally range between 0.023 and 0.099 per cent (Crane and Horrall 1943).

Cholesterol is a high molecular weight alcohol which is soluble in fat and is present in butterfat to the extent of 0.25 to 0.45 per cent.

The yellow coloring materials in butterfat, carotene and xanthophyll, are made up of roughly 90 per cent carotene and ten per cent xanthophyll. The fat soluble vitamins, vitamin A and vitamin D, are also present in butterfat. These materials vary somewhat from season to season depending on the nature of the feed given to the cow.

TABLE 36

TYPICAL FATTY ACID ANALYSES OF SOME FATS OF ANIMAL AND PLANT ORIGIN[1]
(ALL VALUES IN WEIGHT PERCENTAGE)[2]

	Saturated			Unsaturated		
	Palmitic	Stearic	Other[3]	Oleic	Linoleic	Other
Animal Fats						
Lard	29.8	12.7	1.0	47.8	3.1	5.6[4]
Chicken	25.6	7.0	0.3	39.4	21.8	5.9[4]
Butterfat	25.2	9.2	25.6	29.5	3.6	7.2[4]
Beef fat	29.2	21.0	3.4	41.1	1.8	3.5[4]
Vegetable Oils						
Corn	8.1	2.5	0.1	30.1	56.3	2.9
Peanut	6.3	4.9	5.9	61.1	21.8	..
Cottonseed	23.4	1.1	2.7	22.9	47.8	2.1
Soybean	9.8	2.4	1.2	28.9	50.7	7.0[5]
Olive	10.0	3.3	0.6	77.5	8.6	..
Coconut	10.5	2.3	78.4	7.5	Tr.	1.3

[1] Anon. 1958.

[2] Compositions are in weight percentages of component fatty acids. If values as glycerides are desired, the percentages may be multiplied by the approximate factor, 0.95.

[3] Values in this column for butterfat and coconut oil are due to large amounts of acids C_{12} and below. Peanut oil contains several per cent of C_{20} and above acids.

[4] Mainly hexadecanoic acid; 0.2 to 0.4 per cent arachidonic acid.

[5] Mostly linolenic acid.

The enzyme lipase, while not a constituent of butterfat, is of practical concern in a discussion of butterfat because of its lipolytic activity on fats if dairy products are not properly handled in the different phases of processing. Certain types of temperature shock (warming and cooling) and certain processing treatments (homogenization) can greatly accelerate lipolytic activity. Heat treatments of 140°F. and preferably higher in the initial stages of processing are usually adequate for the destruction of the lipolytic enzyme.

Protein.—The classical nomenclature for milk proteins shows them to contain casein, lactalbumin, and lactoglobulin. Modern techniques of protein chemistry have revealed that some of these classical fractions consist of mixtures of different proteins and that others are rather homogeneous in nature. These later developments have resulted in a revision of the nomenclature of milk proteins to conform to these findings.

There have been eight reasonably pure and homogeneous proteins isolated from milk. These proteins are listed in Table 37 which shows the classical fraction from which each is isolated and the approximate percentage of each.

Table 37[1]

INDIVIDUAL PROTEINS OF MILK AND THEIR APPROXIMATE PERCENTAGE OCCURRENCE

Protein	Classical Fraction From Which Isolated	Approximate[2] Percentage Occurrence
Alpha casein	Casein	45–63
Beta casein	Casein	19–28
Gamma casein	Casein	3–7
Beta lactoglobulin[3,4]	Lactalbumin	7–12
Alpha lactalbumin[3]	Lactalbumin	2–5
"Blood" serum albumin[5]	Lactalbumin	0.7–1.3
Immune globulins		
Euglobulin	Lactoglobulin	0.8–1.7
Pseudoglobulin	Lactoglobulin	0.6–1.4

[1] Jenness *et al.* (1956).

[2] As determined by measurements of relative areas of electrophoretic components in casein (1.5 per cent) and serum protein (2.4 per cent) fractions at pH 8.6 and 0.1 ionic strength.

[3] Prefixes alpha and beta for alpha-lactalbumin and beta-lactoglobulin were assigned on the basis that these proteins sediment at the same rates in the ultra-centrifuge as peaks designated alpha and beta for skimmilk by Pederson.

[4] Beta-lactoglobulin appears to consist of two closely related components designated beta and beta lactoglobulin which differ slightly.

[5] Some of the data for this protein are for material actually isolated from blood.

The proteins of milk can be further defined based on their method of separation from milk (Jenness *et al.* 1956). This may be helpful to some technologists in studying the literature on this subject.

Casein.—The classical casein fraction of milk consists of the fraction precipitated from raw skimmilk by acidifying to pH 4.6 to 4.7. It comprises about 80 per cent of the proteins of milk and consists of a mixture of the three principal components: alpha, beta, and gamma caseins. Casein exists in milk in complex particles containing calcium phosphate.

Milk Serum Proteins (or Whey Proteins).—The proteins of skimmilk, other than casein, comprising about 20 per cent of the total milk proteins.

Heat-labile Milk Serum Protein.—The portion of the milk serum proteins (about 80 per cent) that is rendered acid precipitable at pH 4.6 to 4.7 by previous heat treatment of the milk, (e.g., by boiling for 20 minutes).

Albumin or Lactalbumin Fraction.—The portion of the milk serum proteins that is soluble in neutral one-half saturated ammonium sulfate or saturated magnesium sulfate.

Globulin or Lactoglobulin Fraction.—The portion of the milk serum proteins that is insoluble in neutral one-half saturated ammonium sulfate or saturated magnesium sulfate.

Commercial Lactalbumin.—A product precipitated by heating acidified whey and including both the lactalbumin and lactoglobulin fractions.

Proteose-peptone Fraction.—The portion of the milk serum proteins that is not rendered acid precipitable at pH 4.6 to 4.7 by previous heat treatment of the milk.

Fat Globule "Membrane" Proteins.—A complex of proteins and enzymes including lipoproteins, alkaline phosphatase, and xanthine oxidase adsorbed on the surface of milk fat globules. This material (or at least a fraction thereof) can be isolated by washing cream and churning.

A recent review (Whitney 1958) shows milk contains a rather heterogeneous group of proteins which are present in small quantities and whose significance in baking technology is not, at this time, fully understood.

The somewhat detailed classification and description of milk proteins is presented here because it is this fraction of milk solids that is of major concern in baking, particularly in the case of yeast raised doughs where gluten structure plays a role in the physical dough character. It is, in fact, the effect of heat on the various protein components of milk that is the basis for much of the technology of milk processing for bakery use.

Lactose.—Lactose or milk sugar is a reducing disaccharide which breaks down on hydrolysis by acids or by the enzyme lactase to the monosaccharides, glucose and galactose. The ordinary lactose of commerce is alpha lactose monohydrate which melts at 362.9°F. and has a specific rotation of +89.40° (for the anhydrous sugar). When dissolved in water it undergoes mutarotation; the equilibrium solution contains 37.8 per cent of the alpha and 62.2 per cent of the beta form to give a constant specific rotation of +55.5°. If lactose is crystallized from solution above 200.3°F. anhydrous beta lactose, with a specific rotation of +35.0° and a melting point of 453.6°F. is produced. When an equilibrated solution is very rapidly dried by means of a drum or spray drier, the resulting solid is an amorphous glass containing the alpha and beta forms in approximately the equilibrium ratio present in solution. By drying more slowly above 200.3°F. the ratio of the beta to the alpha form is increased, and under appropriate conditions practically pure beta lactose can be obtained.

Alpha-lactose monohydrate is less soluble in water and less sweet than the anhydrous beta form. The solubility of lactose (equilibrium mixture of alpha and beta forms) at 32.0°F. is only 12 gm. per 100 gm. of water as compared with 179 gm. per 100 gm. of water for sucrose. The sweetness of lactose in comparison with sucrose as 100, is 16 (Gortner and Gortner 1949). Lactose is readily converted to lactic acid by many microorganisms but is not fermented to alcohol by common yeast.

Minerals.—The mineral content of fluid whole milk is approximately as follows:

Mineral	Percentage
Calcium	0.112
Phosphorus	0.095
Potassium	0.138
Magnesium	0.013
Sodium	0.095
Chlorine	0.109
Sulfur	0.010

Also present in small amounts are iron, 3.0 p.p.m.; zinc, 3.0 p.p.m.; silicon, 2.0 p.p.m.; copper, 0.3 p.p.m.; and fluorine, 0.15 p.p.m.

The minerals of milk aside from playing a fundamental role in nutrition, have a bearing on the heat stability of milk. In the manufacture of evaporated and condensed milks and certain types of milk powders, this mineral balance between calcium and magnesium on the one hand, and phosphates and citrates on the other, is fundamental to the production of products having uniform viscosity characteristics. The first two minerals tend to cause protein coagulation, while the latter two compounds tend to prevent it. Hence, if a batch of milk contains an excess of calcium, the correct balance could be obtained by the addition of sodium phosphate. Citric acid aids in maintaining the salt balance by forming salts with calcium and magnesium.

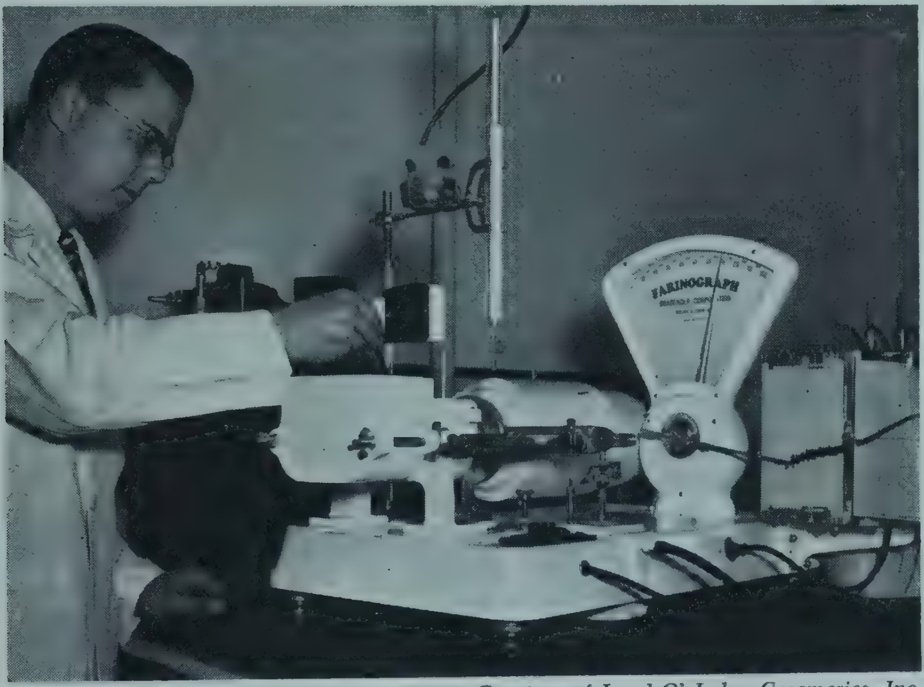
The Effect of Heat Treatment on Baking Quality

The preceeding discussion has dealt with the basic composition and characteristics of milk and its component parts. The behavior of milk or milk solids in a baking operation is dependent on the conditions used in the various manufacturing processes.

Whey Protein Denaturation.—The effect of heat treatment of milk on its baking behavior has been recognized for many years. The pioneer work of Greenbank *et al.* (1927) showed that heat treatment of separated milk prior to drying improved the baking quality of the resulting nonfat dry milk. The work of Skovholt and Bailey (1932) demonstrated that heat treatment of skimmilk reduced the tendency of doughs to slacken upon extended mixing. Later Stamberg and Bailey (1942) demonstrated that the dough softening fraction of milk was concentrated in the whey portion. This was later demonstrated to be associated with the serum protein (or whey protein) fraction. More recent work based on the bake testing of the individual constituents of milk before and after heat treatment has further demonstrated that the loaf volume depressant is concentrated in the whey protein with the casein and lactose playing a relatively minor role.

The minimum heat treatment required for whey protein denaturation and satisfactory baking quality has been reported as 163.4°F. for 30 minutes. Since somewhat higher temperatures are not harmful, preheat temperatures in the order of 185.0°F. for 20 to 30 minutes are commonly used in the commercial processing of skimmilk for bakery use.

Research workers are still looking for the specific fraction or fractions of the whey protein portion of milk which carries the loaf volume depressant and are attempting to determine the exact chemical phenomenon involved. Nonetheless, there is general agreement that the heat treatment of skimmilk, and more specifically of the serum protein fraction of skimmilk, is the practical solution for the production of improved baking quality nonfat dry milk.



Courtesy of Land O' Lakes Creameries, Inc.

FIG. 28. THE FARINOGRAPH BEING USED TO DETERMINE WATER ABSORPTION OF SPRAY PROCESS NONFAT DRY MILK

Water Absorption.—The desirability of using milk products with high water absorbing capacity has been generally recognized in bread making. This characteristic of dry milk is associated with the degree of destabilization of the casein. Since the caseins are considerably more stable to heat treatment than the serum protein fraction of milk, the caseins are sometimes said to be "undenaturable" in that their solubility is not affected by the usual heat treatments used in dairy processing (140° to 200°F. for up to five hours). More drastic heat treatments do cause coagulation or partial coagulation of these proteins. This principle is utilized in many milk processing techniques where high viscosity and high water or fat absorbing characteristics are desired in finished products.

The effect of heat treatment on the physical characteristics of casein is dependent upon the stage of processing where heat is applied. Fluid milk or fluid skimmilk will require prolonged heat treatment for casein destabilization. Increasing the solids concentration during the condensing and drying operation (up to about 90 per cent solids) will rapidly alter the sensitivity of caseins to heat destabilization. For this reason fluid skimmilk (about nine per cent total solids) is usually preheated before concentrating to achieve whey protein destabilization (see p. 109) while the concentrated milk (about 40 per cent total solids) is heated to temperatures ranging from 170 F. to 200 F. to achieve casein destabilization and higher water absorption. A knowledge of the characteristics of casein and the greater heat sensitivity of the serum proteins makes it possible to adjust processing procedures in the manufacture of condensed and dry milk products to secure the desired serum protein denaturation and casein destabilization for any particular bakery use.

Effect of Milk Solids on Bakery Products

Certain changes occur when milk solids are added to doughs. These changes manifest themselves at different times and in different manners during the dough making and baking process. Specific chemical explanations of what happens when nonfat dry milk is added to a flour dough are not fully known because of the extreme complexity of the system.

Absorption and Dough Strengthening.—Properly processed nonfat dry milk appears to act as a strengthening agent to flour proteins. This manifests itself in increased loaf volume and is more evident when milk solids are used with medium strength flours than with strong flours. While unheated whey proteins are generally associated with undesirable effects on the gluten structure of doughs, the casein fraction of nonfat dry milk contributes to proper absorption. Properly heat treated milk will, in fact carry 100 to 125 per cent of its weight in water as compared to 58 to 64 per cent for most bread flours. This higher absorption characteristic of milk is of definite economic significance when considering the level of milk solids to use in any baked product. Indeed it is a factor to be considered when evaluating different sources of milk solids for bakery use.

Mixing Tolerance.—With modern high speed mixers, improved grain, texture, color, and eating qualities of bread can be achieved. Increased absorption can also add to bread yields if optimum mixing times are adhered to. The inclusion of nonfat dry milk will result in doughs which are more tolerant to over-mixing than water doughs. Milk doughs will recover more rapidly and show little evidence of over-mixing by the time they reach pan stage.

Fermentation.—During fermentation there is a definite increase in dough acidity. The addition of nonfat dry milk to a dough will usually slow down this acid development resulting in lower acidities than with corresponding water doughs throughout the entire fermentation period. These lower acidities are due largely to the buffering action of the milk. Since milk doughs will average pH 5.5 and water doughs 5.1, it is reasonable to expect that diastases with an optimum pH range in the order of 4.7 would be somewhat slowed. The addition of diastatic malt in conjunction with nonfat dry milk can result in a very marked improvement in baking performance when flours of low diastatic activity are involved.

Nonfat dry milk will generally result in extended fermentation times in bread doughs. This extended fermentation tolerance is a definite advantage in bread production in that the milk acts as a dough stabilizer permitting the production of satisfactory bread through a longer fermentation period. It is important, however, that milk doughs be given sufficient fermentation time and not be taken on the "young" side.

Color.—Nonfat dry milk has been recognized as contributing to a golden brown crust color of finished baked bread. Toasting qualities are likewise somewhat improved in milk bread as compared to water bread. While this characteristic has been attributed to the lactose content of the milk, it is possible that lactose, caseins and whey proteins all contribute to browning in some degree.

Grain and Texture.—The grain and texture of the finished bread are also improved by the use of nonfat dry milk. A soft velvety texture and a grain of small uniform cells characterize the crumb of milk bread. This contributes to improved crumb color in that the finer texture and small cell structure create the light velvety appearance. Slicing quality is, in turn, improved as a result of the uniformity of grain and texture.

Loaf Volume.—While loaf volume can be achieved in a number of ways, the proper incorporation of milk in dough will result in increased loaf volume. Experimental bake tests with good milk will consistently show a 5 to 10 per cent increase in loaf volume. In commercial production, however, this increase in loaf volume is relatively minor.

Keeping Quality.—Bread staling involves many factors other than moisture content. The higher moisture content of milk bread permits it to remain soft for longer periods than bread made without milk and, therefore, it has apparent longer keeping quality. There is little evidence to relate milk content to rate of mold development in bread. Shop sanitation and handling methods during cooling and wrapping are of greater fundamental importance in keeping mold development at a minimum.

Nutrition. The nutritional improvement of bread as a result of the incorporation of nonfat dry milk has been the subject of numerous investigations. It is generally agreed that the liberal use of milk in bakery products brings about nutritional improvements that could be secured in no other way. Water bread is known to be rich in carbohydrates and low in minerals, proteins and vitamins. It is relatively simple by the use of any form of milk to increase the mineral content of bread, to improve its protein quality and to supplement its carbohydrates. Indeed, the inclusion of nonfat dry milk in bread will complement the nutrients of water bread to produce a loaf of near perfect dietary quality.

Wheat flour is generally considered to be deficient in the essential amino acids, lysine, tryptophan and methionine. The inclusion of milk solids at a six per cent level will increase the lysine content of bread by 46 per cent, the tryptophan by 10 per cent and the methionine by 23 per cent. Nutritionists have, for years, contended that calcium and riboflavin are two nutrients most likely to be deficient in the American diet. In this respect, the use of six per cent nonfat dry milk in bread will increase the calcium content by 66 per cent and the riboflavin by 13 per cent. From this it is apparent that liberal use of milk solids could result in a loaf of bread justifying sensational dietary claims.

TABLE 38

ESSENTIAL AMINO ACID CONTENT OF DAIRY PRODUCTS[1]
(GM. PER 100 GM. OF EDIBLE PORTION)

	Dry Whole Milk	Nonfat Dry Milk	Casein	Dry Whey
Isoleucine	1.648	2.271	6.550	.734
Leucine	2.535	3.493	10.048	1.043
Lysine	2.009	2.768	8.013	.769
Methionine	.632	.870	3.084	.188
Phenylalanine	1.251	1.724	5.389	.323
Threonine	1.191	1.641	4.277	.677
Tryptophan	.364	.502	1.335	.147
Valine	1.774	2.444	7.393	.640

[1] Anon. 1957.

It should be mentioned here that the amino acid tryptophan has been demonstrated to be a precursor of niacin in man as well as in many other species. In the light of this information, it has been recommended (Anon. 1957) that the niacin content of milk and other food materials be expressed as "niacin equivalent." This value includes the niacin value of the tryptophan plus the actual niacin content of food. Such a calculation will give the nonfat solids of milk a "niacin equivalent" of 9.4 mg. per 100 gm. as compared to 1.1 mg. per 100 grams as listed in most earlier literature. Table 38 summarizes the amino acid contents of dairy products.

Flavor and Eating Quality.—Perhaps the greatest advantage of milk solids in bread and the one which is of immediate interest to commercial bakers is the improved eating quality of bread made with milk. Carefully controlled studies of the acceptability of milk versus water bread have been made by a number of workers in different sections of the country. The data of one of these studies from a California boy's school are typical of these results (Jack and Haynes 1951):

INCREASED CONSUMPTION AS RELATED TO MILK LEVEL IN BREAD

Level of Nonfat Dry Milk, Per cent	Increased Consumption Over Water Bread, Per cent
0	...
6.0	4.4
10.0	7.5
14.0	12.6

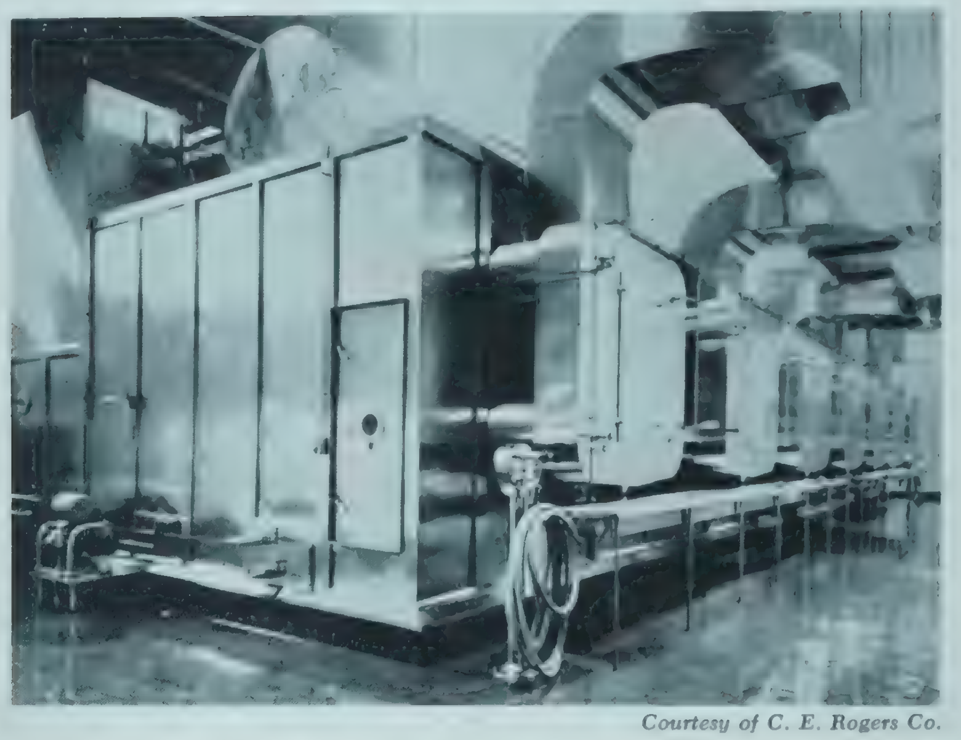
Of interest in relation to the above data is a recent report (Rogers and Welton 1959) showing excellent eating quality for bread containing 25.0 per cent nonfat dry milk in the formula. This leads one to speculate about the possibilities of formulations of this nature for the production of speciality high protein loaves and other types of dietary baked goods.

Milk Solids in Cakes.—Typical milk solids levels in different classes of cake vary from 0 per cent in sponge and angel food, up to 4 to 8 per cent in devil's food and chocolate, to 10 to 12 per cent in white and yellow layer cakes. Milk solids in cakes are credited with (1) contributing to greater moisture retention, and, therefore, longer apparent freshness and keeping quality; (2) improved appearance and crust color and absence of greasiness; (3) improved flavor, richness and taste appeal; and (4) improved nutritional value.

Dry buttermilk works especially well in devil's food and other chocolate cake mixes. The milk fat content and the lecithin of the buttermilk seems to complement and mellow the chocolate flavors to produce cake which is somewhat different but very pleasing in taste and appearance. Dry buttermilk may be used interchangeably with nonfat dry milk in this type cake formula.

There is some evidence (Hanning and deGoumois 1952) that the use of whey solids results in cakes of improved flavor and moistness as compared to those made from nonfat dry milk. In these same studies it was found that whey solids could be substituted for a part of the fat in the formula without having any detrimental effect on texture, tenderness, or flavor.

There is little published evidence on the effect of specific heat treat-



Courtesy of C. E. Rogers Co.

FIG. 29. A MODERN SPRAY DRIER FOR NONFAT DRY MILK

ments on the suitability of dry milks or wheys in their performance in cake batters. Different commercial users prefer products which have received opposite extremes of heat treatment.

Milk Solids in Doughnuts.—Little information is available in the literature regarding specific requirements for nonfat dry milks used in doughnuts and doughnut mixes. There is a general concern about absorption qualities with a tendency towards selecting milk solids of relatively high water absorption values for this use. There is likewise general concern about low fat absorption with attempts to achieve this through proper selection of ingredients.

Bacteriology

The heat treatment which milk receives in processing has a definite effect on its bacteriological quality. Raw or unheated milk can contain appreciable numbers of many types of bacteria. While the majority of these are non-pathogenic organisms of the lactic acid type, there is nothing to preclude the presence of pathogens as well. Pasteurization has been employed to virtually guarantee the destruction of pathogenic organisms in most dairy products. The heat treatment of pasteurization destroys all pathogens and most lactic acid producers and usually achieves better than 99 per cent reduction in total bacteria counts on pasteurized dairy products. Consequently, Standard Plate Counts of pasteurized dairy products should be well below 20,000 per ml. of product. Any remaining organisms are largely spore formers and thermoduric or thermophilic types.

Heat treatments considerably above pasteurization are employed in the processing of most concentrated and dry milk products. As a matter of fact, there are commercial processes which will render many of these products virtually sterile or at least reduce bacteria populations to extremely low numbers. Bakers and technical bakery personnel may, on occasion, have need for dairy products with some of these very specific bacteriologic qualities. Many of the larger dairy processing firms are well qualified to advise and assist bakery technicians with special product problems of this nature. In such instances, it is suggested that the baking technologists seek this information from the dairy technologists so as to arrive at final products and quality standards that are adequate for the special needs of the baker and yet are practical and compatible in terms of basic dairy processing.

PHYSICAL CHARACTERISTICS OF THE VARIOUS FORMS OF MILK

Whole milk and milk products may be classified in three categories depending on their physical form: (1) fluid milk products; (2) concentrated milk products; and (3) dried milk products.

Fluid Milk Products

Fluid milk products include whole milk, skimmilk, buttermilk, and whey. These products are characterized by containing relatively large percentages of water (see Table 39). They are bulky and require extensive storage facilities. They are quite perishable and must be kept under refrigeration. Further, because of their great bulk and perishability, storage and freight costs are high, thus making them relatively high cost ingredients, except in areas where local supplies may lend themselves to bakery usage. The keeping qualities of fluid milk products must be measured in terms of days, even under ideal production, transportation and storage conditions. For these reasons, the economic significance of fluid milks as bakery ingredients is indeed small.

Concentrated Milk Products

Concentrated milks include whole milk, skimmilk, buttermilk, and whey from which a major portion of the water has been removed (see Table 39). These products are referred to as "condensed" if only water has been removed, "sweetened condensed" if sucrose has been added

Table 39

APPROXIMATE COMPOSITION OF DAIRY PRODUCTS AVAILABLE FOR BAKERY USE[1]

Product	Butter Fat	Protein	Milk Sugar	Minerals	Water
Fluid whole milk	3.9	3.5	4.9	.7	87.0
Fluid skim	.1	3.5	5.1	.8	90.5
Cream 20 per cent butterfat	20.0	2.9	4.0	.6	72.5
Cream 30 per cent butterfat	30.0	2.5	3.6	.5	63.4
Cream 40 per cent butterfat	40.0	2.1	3.1	.5	54.3
Plastic cream, 80 per cent butterfat	80.0	.7	1.0	.2	18.1
Milkfat (butteroil)	99.9	.0	.0	.0	.1
Butter (unsalted)	81.0	.6	.4	.5	17.5
Butter (salted)	81.0	.6	.4	2.5	15.5
Buttermilk	.1	3.5	5.1	.8	90.5
Cheddar cheese	32.2	25.0	2.1	3.7	37.0
Cheese whey	.3	.9	5.1	.5	93.2
Process American cheese	29.9	23.2	2.0	4.9	40.0
Dry whole milk 28 per cent butterfat	28.7	25.2	36.9	6.0	3.2
Dry whole milk 26 per cent butterfat	26.7	25.8	38.0	6.0	3.5
Nonfat dry milk	1.0	35.6	52.0	7.9	3.5
Dry buttermilk solids	5.0	34.7	49.0	7.8	3.5
High acid buttermilk solids (5.0 per cent lactic acid)	5.0	34.5	43.7	7.8	4.0
Dried whey	1.2	12.5	72.4	7.7	6.2
Plain cond. whole milk	8.5	7.8	11.9	1.8	70.0
Plain cond. skim milk	.2	11.1	16.2	2.5	70.0
Plain cond. whey	.6	10.1	51.3	6.0	32.0
Evaporated milk	7.9	7.0	9.9	1.5	73.7
Sweetened cond. whole milk (42.0 per cent sucrose)	8.6	7.7	12.2	1.6	27.9
Sweetened cond. skim milk (42.0 per cent sucrose)	.2	11.1	16.2	2.5	28.0
Sweetened cond. whey (38.0 per cent sucrose)	.3	5.6	28.7	3.4	24.0
Lactose	..	..	99.85	..	.15
Sodium caseinate	1.5	90.0	1.0	4.0	3.5

[1] Anon. 1950.

and water removed, and "evaporated" if water has been removed and the end product canned and sterilized to destroy all living organisms. In concentrated milk products the increased total solids content, with the obvious concentration of lactose, plus added sugar in some instances, results in finished products which have keeping qualities varying from weeks to months. They also occupy considerably less storage space and can consequently be transported relatively great distances. Generally, however, refrigeration and rather careful supply arrangements and inventory control are required to incorporate concentrated milks in a bakery production program. Concentrated milk products are generally viscous fluids which lend themselves to certain bulk handling and liquid metering operations.

Dairy products such as cream, butter, cheese, and cottage cheese are concentrated in the sense that butterfat and/or solids not fat have been increased. In commercial terminology, however, they are not usually included in this category.

Dried Milk Products

Dried milk products represent the same products as discussed under fluids and concentrates except that they have had practically all of their moisture removed and are characterized as powders. These products far exceed the fluids and concentrates in commercial significance to the baker. They have the advantages of occupying a minimum of storage space, having very lengthy keeping quality, and requiring no refrigeration. These advantages lend themselves to dependability and uniformity of supply, ease of inventory control, plus uniformity of quality and relatively stable pricing.

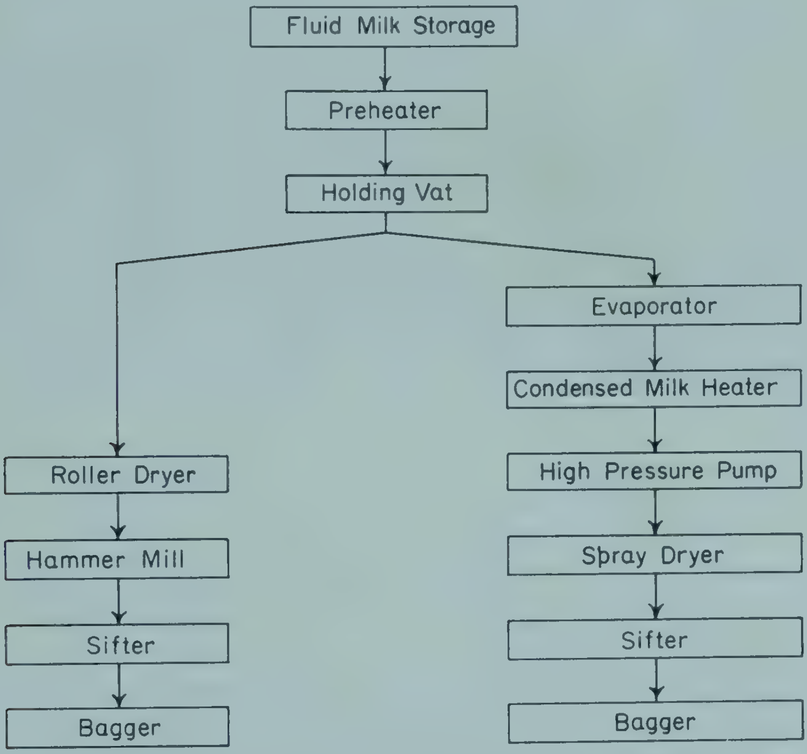
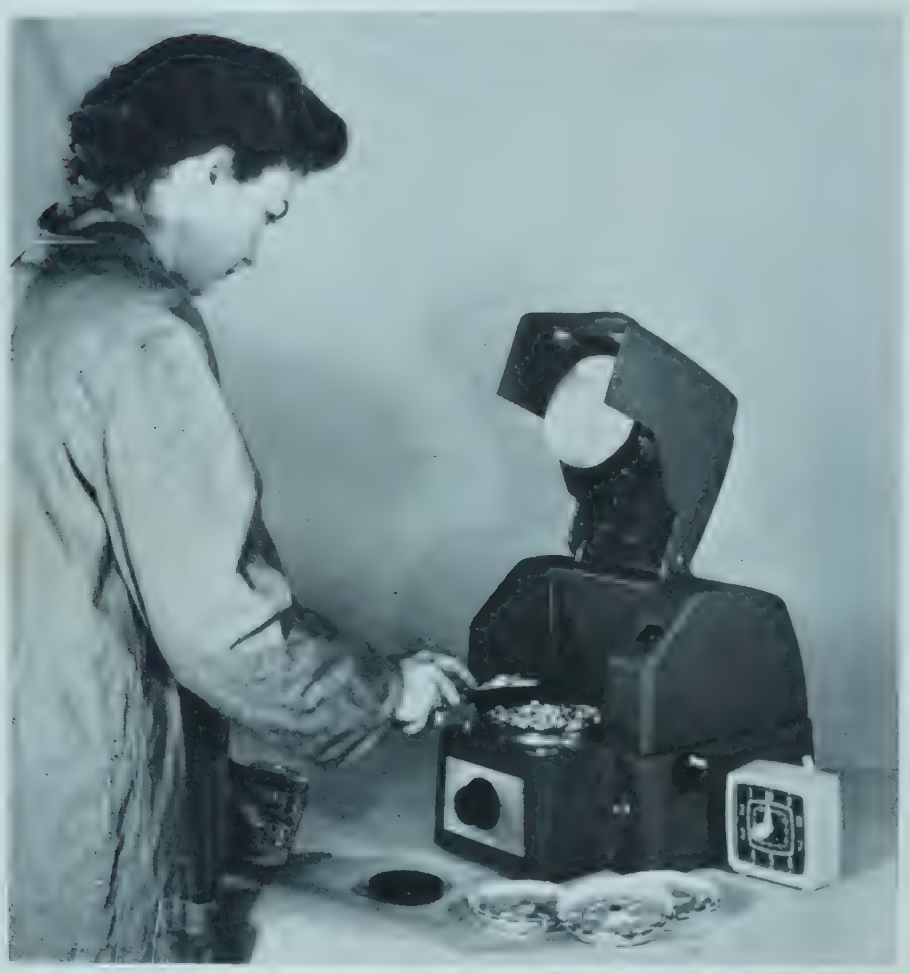

Fluid Milk Storage
Preheater
Holding Vat
Evaporator
Condensed Milk Heater
High Pressure Pump
Spray Dryer
Sifter
Bagger
Roller Dryer
Hammer Mill
Sifter
Bagger

FIG. 30. FLOW DIAGRAM FOR ROLLER AND SPRAY PROCESS MILK POWDER

Dry milks are available in two general forms; either as spray dried or roller dried products. Spray dried products are produced by atomizing the fluid milk into a hot air stream where water is evaporated at temperatures somewhat lower than 212°F. The spray drying process results in powder with relatively little apparent heat damage. On reconstitution



Courtesy of Central Scientific Co.

FIG. 31. AN INFRARED MOISTURE METER FOR RAPID MOISTURE DETERMINATIONS ON NONFAT DRY MILK

with water all of the proteins remain in suspension and flavor qualities are of a bland to mild cooked nature. The powder particles are generally spherical in shape, and range from less than 10 microns up to about 150 microns in size.

Roller dried products are produced by flowing milk in a thin film over steam heated rolls. The dried film is continuously removed from the rolls by scraper blades and the milk film pulverized to varying degrees to produce roller process powder. In the course of drying, this film of milk is exposed to temperatures somewhat in excess of 212 F. with consequent denaturation of much of the protein system of the milk or milk product. The roller process results in powder with considerable cooked or even a slight scorched flavor. On reconstitution a large portion of the protein does not remain in suspension and settles to the bottom of the container. Roller process powder particles may vary from very small particles up to large flakes easily distinguished as such by the naked eye. The specific size range of these flakes can be controlled within reasonable limits to satisfy different users.

Aside from the general classification of fluids, concentrates, and powders, milk products for use in baking are available in many forms. Many of these have been standardized to the degree that they are commercial products, defined by standards of identity, act of Congress, or by industry established standards. Others fall in the category of being specialty products of compositions to satisfy the needs of individual users. Still others may be classified as mixtures of milk ingredients and any number of related food materials and may bear trade names which are often associated with commercial secrecy and sometimes enjoy varying degrees of patent protection.

Table 39 summarizes the composition of the more important commercially available dairy products and shows their typical composition.

As a general guide it can be assumed the baking behavior of any of the dairy products listed in Table 39 can be predicted on the basis of its composition (see page 116). Products such as dry whole milk, cream or butter, for example, will contribute to the finest flavor as a result of their high butterfat content. Nonfat dry milks, on the other hand, will carry the characteristics of milk proteins and lactose, whereas wheys, lactose or caseinates must be considered on the basis of their respective major food constituents. Further, the moisture content of all products must be considered in balancing formulas and in calculating costs.

Nonfat Dry Milk.—Nonfat dry milk is defined as the product resulting from the removal of fat and water from milk, and contains the lactose, milk protein and milk minerals in the same relative proportions as in the fresh milk from which made. It contains not more than five per cent by weight of moisture. The fat content is not over one and one-half per cent by weight unless otherwise indicated. Nonfat dry milk is available as either *spray* or *roller process* (see p. 117). It is available in either *Extra Grade*, indicating the highest quality, or *Standard Grade*, if it fails to meet the *Extra Grade* requirements.

EXTRA GRADE REQUIREMENTS OF NONFAT DRY MILK

	Spray Process (Not greater than)	Roller Process (Not greater than)
Butterfat	1.25 per cent	1.25 per cent
Moisture	4.0 per cent	4.0 per cent
Titratable acidity[1]	0.15 per cent	0.15 per cent
Scorched particle	15.0 mg.	22.5 mg.
Solubility index[1]	1.25 ml.	15.0 ml.
Bacterial estimate	50,000 per gram	50,000 per gram

[1] Determination made upon reliquified sample.

Dry Whole Milk.—Dry whole milk is the product resulting from the removal of water from milk and contains not less than 26 per cent milk fat and not more than four per cent moisture. It is available as either spray or roller process (see p. 117), though spray process is of greater economic significance. Dry whole milk is available in either *Extra Grade*, indicating the highest quality, or *Standard Grade*, if it fails to meet *Extra Grade* requirements.

EXTRA GRADE REQUIREMENTS OF DRY WHOLE MILK

	Spray Process	Roller Process
Butterfat (not less than)	26.00 per cent	26.00 per cent
Moisture (not more than)	2.50 per cent	3.0 per cent
Titratable acidity[1] (not more than)	0.15 per cent	0.15 per cent
Bacterial estimate (not more than)	50,000 per gm.	50,000 per gm.
Solubility index (not more than)	0.50 ml.	15.00 ml.
Scorched particle (not more than)	15.0 mg.	22.5 mg.
Copper	1.5 p.p.m.	1.5 p.p.m.
Iron	10.0 p.p.m.	.....
Flavor-odor	Normal	Normal
Color	Normal	Normal

[1] Determination on reliquified sample.

Dry Buttermilk Solids.—Dry buttermilk solids is the product resulting from the removal of water from liquid buttermilk derived from the manufacture of butter. It shall contain not less than four and one-half per cent butterfat and not more than five per cent moisture. Dry buttermilk is available in either spray or roller process and is graded as *Extra Grade*, indicating the highest quality, and *Standard Grade* for product failing to meet these requirements.

EXTRA GRADE REQUIREMENTS OF DRY BUTTERMILK SOLIDS

	Spray Process	Roller Process
Butterfat (not less than)	4.50 per cent	4.50 per cent
Titratable acidity[1] (not less than)	0.10 per cent	0.10 per cent
(not more than)	0.18 per cent	0.18 per cent
Bacterial estimate (not more than)	50,000 per gm.	50,000 per gm.
Scorced particles[1]	15.0 mg.	22.5 mg.
Alkalinity of ash[2]	125 per ml.	125 per ml.
Moisture (Not more than)	4.00 per cent	4.00 per cent
Solubility index[1]	1.25 ml.	15.0 ml.

[1] Determination made upon reliquified sample.
[2] Milliliters of 0.1 N HCl per 100 gm.

High Acid Buttermilk Powder.—High acid buttermilk powder (or cultured buttermilk powder) is the product resulting from the drying of liquid buttermilk which has been cultured to produce the desired acidity prior to drying.

EXTRA GRADE REQUIREMENTS OF HIGH ACID BUTTERMILK

Butterfat (not less than)	4.5 per cent
Titratable acidity[1] (not less than)	.50 per cent
Moisture (not more than)	5.0 per cent

[1] Determination on reliquified sample.

Dry Whey.—Dry whey is the product resulting from spray drying sweet, fresh, cheese whey which has been pasteurized either before or during the process of manufacture at a temperature of 143°F. for 30 minutes or its equivalent in bacterial destruction and to which no chemical has been added.

U. S. EXTRA GRADE REQUIREMENTS OF DRY WHEY

Butterfat content	Not more than 1.25 per cent
Moisture content	Not more than 5.00 per cent
Scorched particle content	Not more than 15.0 mg.
Solubility index[1]	Not more than 1.25 ml.
Titratable acidity[1]	Not more than 0.16 per cent
Alkalinity of ash	Not more than 225 ml. 0.1 N HCl per 100 gm.
Flavor and odor	Free from non-whey flavors and odors
Bacterial estimate	Not more than 50,000 per gm.
Physical appearance	Has a uniform light color; free from lumps that do not break up under moderate pressure; and practically free from brown and black scorched particles

[1] Determination on reliquified sample.

Lactose.—Lactose is the pure crystalline sugar obtained from milk. Its chemical and physical specifications are as follows (Reger 1957):

Moisture	Not more than 1.50 per cent
Acidity, as lactic	Not more than .04 per cent
Lactose, monohydrate	Not less than 98.0 per cent
Protein (N x 6.25)	Not more than 0.30 per cent
Ash	Not more than 0.4 per cent
Fat (ether extractable)	Not more than 0.25 per cent

Edible Sodium Caseinate.—Edible sodium caseinate (Anon. 1958) is the product resulting from the acid precipitation of casein from fresh skimmilk. This precipitate is redispersed by the addition of mild alkalies and the moisture removed by spray drying. This product has the following chemical and physical specifications:

Protein (N x 6.38)	90.0 per cent
Fat	1.5 per cent
Ash	4.0 per cent
Moisture	3.5 per cent
Reducing substances	2 per cent (maximum)
pH (2 per cent solution)	6.4–6.8
Sodium	1.5 per cent
Color, flavor and odor	Cream white, bland and clean
Particle size	Through 100 mesh
Sediment	15.0 mgs.
Bacteria	
Standard plate count	Less than 30,000 per gm.
Thermophile count	Less than 20,000 per gm.
Yeast and mold	Less than 100 per gm.
Coliform	Negative

GENERAL QUALITY TESTS FOR MILK AND MILK PRODUCTS

Each type of milk has its own peculiar, yet important specifications. There are certain of these that are common to all types of milk and are indicative of the over-all quality, the quality of the processing or the quality of the original raw material used. References are cited for each of these methods for specific details of methodology (Anon. 1949).

Butterfat

Commercially, the butterfat content of most liquid dairy products is determined by the Babcock Test. This test involves a volumetric measurement of the fat present in a previously weighed or measured portion of fluid after the digestion of milk proteins by sulfuric acid.

The somewhat more precise technique for butterfat determination involves the ether extraction of the fat with evaporation of the extracting solvent, and drying of the extracted fat in a vacuum oven, with final gravimetric determination of dry fat from a given weight of sample.

Since milk fat or butterfat is the most costly milk constituent, the pricing of any milk product is necessarily based, to a large degree, on its fat content.

Moisture

While vacuum oven techniques, with drying to constant weight, are the most widely accepted techniques for determining moisture content, there are other more rapid methods that may be used under varying conditions, and where official accuracy is not required.

Lactometer.—The lactometer is a hydrometer calibrated to read in terms of the specific gravity of fluid milk products (Anon. 1949). Under constant temperature conditions fluid milk products of known fat content will vary in specific gravity depending on their solids-not-fat and (by difference) their moisture content. This method is commonly used for production control purposes in fluid and concentrated milk products.

Toluol Distillation.—This method for moisture determination is based on the evaporation of water from a known weight of dry milk product (Anon. 1948). This moisture is in turn condensed and measured volumetrically. Toluol having a boiling point somewhat above that of water is used as the heat transfer media for this purpose. This is the commercial test commonly used for moisture determination in dry milks. High moisture content (above four per cent) in dry milk products will cause rapid flavor deterioration, possible browning of product, and lumping. Low moisture content (below four per cent) of dry milks is, in fact, fundamental to their over-all utility value.

Infrared Moisture Meters.—This moisture test depends on heat from an infrared source to rapidly dry materials (usually powders) to constant weight. This technique is widely used in production control because of its rapidity (five to ten minutes).

Acidity Test

Essentially all fresh milk products are slightly acidic. This acidity is measured by determining the quantity of standard alkali required to neutralize the acidity in a given quantity of milk sample (Anon. 1949). The value is expressed as per cent titratable acidity calculated as lactic acid. Acidities above those known to be normal for any specific milk product are indicative of bacterial decomposition of the product; those below normal indicate neutralization.

Bacteria

The bacteriologic quality of milk products can be estimated by one or more of three general techniques (Anon. 1948, 1949):

Reduction Tests.—These are tests for bacterial activity which can be applied to raw fluid milks. Results are expressed as hours "reduction time" required for methylene blue or resazurin dyes to be reduced to colorless or varying hues of color. These are tests for bacterial activity rather than bacteria numbers, and are usually used in grading of raw milk supplies.

Microscopic Clump Counts.—This technique involves the staining and actual counting of numbers of bacteria in a certain quantity of milk. These counts are usually expressed as clumps per ml. (in the case of fluids) or per gram (in the case of powders). This type of analysis will generally give an estimate of total numbers of bacteria in a material, some of which may be live cells and others dead. The microscopic clump count is widely used for appraising the bacterial quality of raw fluid milk and more recently has been applied as a test for determining the processing history of nonfat dry milk. High microscopic clump counts of nonfat dry milk are generally indicative of poor quality raw milk and/or poor manufacturing practice in processing.

Standard Plate Counts.—The standard plate count is the almost universal industry technique for estimating the living bacterial organisms in raw or pasteurized, fluid, concentrated, or dry milk products. Specifically, it estimates the number of organisms that will grow in the standard plate count media, at 92°F. These counts are expressed as organisms per ml. for fluids or per g. for powders. Since a "plate count" is a measure of viable organisms, it is a quality criterion of particular concern in products and processes where cetain types of fermentations, storage conditions or lengthy shelf life are involved.

There are numerous other tests for bacterial quality where specific organisms are involved. The coliform test, thermophilic spore counts, and blood agar counts are examples of these. Specifications involving such characteristics are often worked out between the supplier and purchaser of milk products.

Flavor and Odor.—The flavor and odor of all sweet milk products should be bland, slightly sweet, and free from acid, feed and other foreign flavor (Anon. 1948, 1949). Flavor and odor of dry milk products are usually determined on a reconstituted basis. With certain types of highly heated milk powders, cooked flavors of varying degrees are to be expected and may even be desirable.

Scorched Particles.—The scorched particle test, formerly referred to as a sediment test, involves the reconstitution of specific quantities of milk powders with filtration through a one and one-fourth inch diameter cotton pad to determine the presence of burned milk particles or any other extraneous material (Anon. 1948). Modern drying techniques should produce powders with a minimum of scorched particles.

Solubility Index.—The solubility index test is performed by reconstituting known quantities of powders under carefully controlled conditions and, after centrifuging to accentuate separation of insoluble material, measuring the quantity of material gathering in the bottom of a centrifuge tube (Anon. 1948).

The solubility index measures the relative quantity of destabilized milk protein (particularly casein) in dry milk powders. A high solubility index can be caused by excessive heat in drying, developed acidity in a raw milk supply, or physiologically unstable milk. Roller process powders are characterized by high solubility indexes while spray process powders characteristically have low solubility indexes (see p. 119).

SPECIAL TESTS FOR BAKING PERFORMANCE

It has been discussed earlier that milk powders used for baking purposes must possess certain qualities beyond the general quality required for *Extra Grade Powder.* Whey protein denaturation and its associated chemistry, water absorption, and, of course, final baking performance are the special qualities required in powders for bakery use.

Harland-Ashworth Whey Protein Test (Kuramoto *et al.* 1959)

Apparatus and Reagents

Test tubes.—25 by 150 mm. lipless, Pyrex or soft glass.

Funnels.—Diameter, 50 mm., stem length, 65 mm.; diameter 90 mm., stem length, 65 mm.

Filter paper.—S & S No. 602, 9 cm., S & S No. 605, 15 cm. pleated filter paper.

Cuvettes.—Optically matched.

Pipettes.—Ostwald-Folin type 1, 2, 3, 4, and 5 ml.; volumetric 5, 10, 20, and 100 ml.

Balances.—(1) Analytical balance for weighing the 2-gm. sample of NFDM. (2) torsion balance (±0.1 gm.) to weigh the salt and the 20 gm. samples of NFDM.

Water bath.—Thermostatically controlled to 98.6° F. (±1°).

Spectrophotometer or colorimeter.—The spectrophotometer or colorimeter being used by the individual laboratory.

Saturated sodium chloride.—Add 1 kg. of cheese or butter salt to two liters of distilled water and heat the mixture to near boiling, with frequent stirring to insure complete saturation. After cooling to room temperature, filter the solution through S and S 605 pleated filter paper. Do not use sodium chloride containing anticaking agents for the preparation of this reagent or for saturation of the sample.

HCl solution (10 g./100 ml.).—23 conc. HCl, C.P. reagent, plus 77 ml. of distilled water.

Standard reference powders.—Low heat NFDM and high heat NFDM.[1]

Nephelometer standard.—N equals 78, Coleman Instruments, Inc., Chicago, Illinois.

Procedure.—Reconstitute two grams of NFDM in 20 ml. of distilled water in a 25 by 150 mm. test tube. Add eight gm. of NaCl, stopper, and place in a water bath at 98.6°F. for 30 minutes. Shake the contents of the tube from 8 to 10 times during the first 15 minutes of the incubation period, to insure complete saturation of the sample with NaCl.

Without cooling, shake mixture to facilitate pouring, and filter through S and S No. 602, 9 cm. filter paper. Refilter through the same filter paper if the first portion of the filtrate is cloudy. Collect approximately five ml. of filtrate.

Pipette a one ml. aliquot of the filtrate into a cuvette. Dilute the filtrate with ten ml. of saturated NaCl solution. Stopper the cuvette with a rubber stopper and mix by slowly inverting once.

Add two drops (delivered from a five ml. volumetric pipette) of the HCl solution, to develop the turbidity. Stopper the cuvette and mix the acid with the diluted filtrate by slowly inverting twice. Care should be taken to prevent the formation of foam.

Within 5 to 10 minutes after adding the acid, invert the cuvette once again and measure the turbidity in the instrument used in the particular laboratory, with the wave length set at 420 millimicrons. Adjust the instrument to 100 per cent transmittance with a diluted casein-free filtrate made by diluting one ml. of the original filtrate with ten ml. of saturated NaCl solution.

Make duplicate determinations on each filtrate and, for each transmittance reading, obtain a value for serum protein nitrogen from the standard curve. Take an average of the duplicates and report as mg. serum protein nitrogen per gm. NFDM.

Duplicates should agree within two per cent transmittance. If they do not, another pair should be analyzed and the average of the four determinations used for the final value.

Preparation of Standard Curve.—Reconstitute 20 gm. (−0.1 gm.) each of the standard low-heat NFDM and the standard high-heat NFDM with exactly 200 ml. of distilled water in 500 ml. Erlenmeyer flasks.

Saturate each reconstituted milk with 80 gm. of NaCl, stopper the flasks, shake for one minute, and incubate at 98.6°F. for 30 minutes. Shake the mixtures from 8 to 10 times during the first 15 minutes to insure complete saturation, allowing them to remain undisturbed for the remainder of the incubation period.

Without cooling or further agitation, except that necessary to permit pouring, filter the mixture through S and S 605, 15 cm. pleated filter paper. In cases where the first portion of the filtrate comes through cloudy, refilter through the same filter. Continue filtration until approximately 100 ml. of filtrate have been collected. Cover the filters with a watch glass during the filtration, to prevent excessive evaporation.

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[1] Available, together with their respective serum protein nitrogen values (Kjeldahl), from American Dry Milk Institute, Inc., Chicago, Illinois.

Pipette proportions of low-heat and high-heat filtrates into 25 by 150 mm test tubes as follows:

Tube No.	Low-Heat Filtrate, Ml.	High-Heat Filtrate, Ml.
1	10	0
2	8	2
3	6	4
4	4	6
5	2	8
6	0	10

Stopper the tubes containing the combined filtrates and mix by slowly inverting the tubes twice.

Pipette one ml. aliquots of the mixed filtrates into cuvettes, dilute with ten ml. of saturated NaCl, and develop the turbidity as described previously.

Plot the standard curve, using serum protein nitrogen values (Kjeldahl) per gram of powder for the horizontal axis and per cent transmittance as the vertical axis on 8.5 by 11 inch graph paper (one mg. SPN equals one inch, ten per cent transmittance equals one inch). It is essential that the difference in transmittance readings between the low-heat and high-heat filtrates be as large as possible, preferably at least 35 per cent.

Day to day reproducibility of the instrument may be checked by use of a nephelometer standard (N equals 78, Coleman Instruments, Inc.).

Interpretation.—Nonfat dry milk for which the Harland-Ashworth Whey Protein Nitrogen test is specific, will contain on the average 9.12 mg. of serum protein per gram solids. The serum protein content of raw skimmilk in different sections of the country can vary between 8.52 mg. and 9.96 mg. per gram solids. Since denaturation of this whey protein fraction is associated with good baking quality, a high degree of denaturation and low level of undenatured serum protein is desirable for a yeast raised dough type of product. Opinions among technologists vary as to specific undenatured whey protein values required in the baking industry. From experience it is apparent that undenatured whey protein values of 1.0 mg./gm. or lower are generally very adequate. Some data (Ashworth and Krueger 1951) would indicate that values of 2.0 mg./gm. or below are satisfactory for most bread making purposes. It should be stated, however, that as whey protein denaturation values drop from 2.0 mg. to 1.0 mg. there is a definite tendency for higher absorption values in the nonfat dry milk. Tentative standards for "high heat" or bakery grade nonfat dry milk have been established by the American Dry Milk Institute as 1.5 mg. or less.

In lieu of the laboratory bake test, the Harland Ashworth Whey Protein Nitrogen test is, perhaps, the most widely used technique for evaluating baking quality of nonfat dry milk. It is used as a control testing procedure by most large producers of nonfat dry milk, as well as by technologists in the baking industry. It is natural, therefore, that it has become a basis for bakery grade specifications in many segments of both industries.

Nonfat dry milk processed with low temperature treatments will show undenatured whey protein nitrogen values in the order of 6.0 to 8.0 mg./gm., indicating the rather substantial difference existing between high heat and low heat nonfat dry milks by this analysis.

The Harland-Ashworth Whey Protein Nitrogen test is applicable to both spray and roller process nonfat dry milks. It is also being used to some degree on dry buttermilk solids for evaluating baking quality though no data have been published supporting this application as of this date.

Courtesy of Land O' Lakes Creameries, Inc.

Fig. 32. A Laboratory for Routine Analyses of Milk Powders

Hoffman-Dalby Farinograph Test

Equipment.—Brabender Farinograph. Laboratory scale or balance.

Method.—The absorption of a spring wheat flour is determined by titrating a 300-gm. sample ("as is" basis) with water until a maximum dough development of 500 Brabender units is obtained (Hoffman *et al.* 1948). Place 150 gm. of flour, 150 gm. of the nonfat milk solids in the farinograph mixer, and add the amount of water computed as follows:

Let F be the absorption of the flour in percentage based on the original titration of the flour.

Then the percentage of water to be added to the mixture will be:

$$\frac{F + 65}{2}$$

(Thus an absorption of 65 per cent is arbitrarily assigned to the milk).

An average sample of nonfat milk solids when mixed with flour will reach the 500 line immediately, but within 30 seconds or so the mixture will soften. After 10 to 14 minutes mixing, the pointer will again reach the 500 line. Then add more water in 1.5 ml. portions, to hold the pointer on the 500 line during further mixing until maximum absorption is measured. Let X be the final absorption of the mixture; the absorption of the nonfat milk solids is:

$$2\left(X - \frac{F}{2}\right)$$

Record two factors: (1) development period (the time required in minutes for mixture to reach a consistency of 500 with the original addition of water); and (2) final absorption of milk.

Spray Powder

The same basic procedure is used for spray as for roller nonfat dry milk except that an original 40.0 per cent absorption is substituted for the 65.0 per cent absorption for roller powder.

Interpretation of Results

Roller Process Powder.—Hoffman *et al.* (1948) reported the following tentative baking quality ratings of milks from results of farinograph tests:

TENTATIVE QUALITY RATINGS OF MILKS FROM RESULTS OF FARINOGRAPH TESTS

Development Period	Per cent Absorption	Rating
Under 10 minutes	Over 70	Excellent
10 to 12 minutes	Over 70	Good
12 to 16 minutes	Over 70	Fairly good
12 to 16 minutes	67 to 70	Fair
Over 16 minutes	Under 67	Poor

These general standards have been used by certain segments of the baking industry as purchase specifications for roller process nonfat dry milk. However, little substantiating evidence has been published supporting this classification.

Spray Process Powder.—Specific farinograph absorption values for spray process nonfat dry milk have not been published. It is known, however, that low heat nonfat dry milks will exhibit absorptions well below 40.0 per cent. High heat powders will vary from about 40.0 per cent to as high as 60.0 per cent. Values of 45.0 to 50.0 per cent are common for high heat powders. Values of 50.0 to 55.0 per cent represent spray process powders of relatively high absorption. When absorption values of over 55.0 per cent are reached, this represents spray powders of exceedingly high absorption. These high absorptions are often, though not always, reflected in somewhat high solubility index readings. It is felt by many that this high solubility index is not of great significance in bakery type powder.

Brookfield Viscosity Test (Nair 1959)

Apparatus Required.—(1) gram scale; (2) Waring blendor; (3) graduated cylinder (500 ml.); (4) spatula; (5) suction flasks (1,000 ml.); (6) vacuum pump and trap set-up; (7) 400 ml. Berzelius beakers; (8) Brookfield Viscosimeter Model LVF; (9) beakers (1000 ml.); and (10) watch glasses for 1000 ml. beakers.

Reagents Required.—(1) distilled water; and (2) defoaming agent (diglycol laurate).

Method.—(1) Weigh 143 gm. of powder; (2) measure 333 ml. of distilled water at 77°F. and add water to Waring blendor; (3) add milk powder; (4) mix for ten seconds; (5) stop mixer and scrape down adhering powder from the sides of the tumbler with a spatula; (6) mix for two more minutes; (7) pour mixture into a one liter beaker and cover with a watch glass; (8) place in a water bath at 77°F. for two hours; (9) just before two hour period ends, remove foam with tablespoon; (10) pour remaining liquid carefully into the liter suction flask and add two drops of diglycol laurate; (11) place flask under full vacuum for a few minutes; hold vacuum treatment to a minimum to avoid moisture loss; about ten minutes is usually sufficient; (12) transfer sufficient liquid to the 400 ml. beaker to reach notch on number one spindle; (13) place beaker in 77°F. water bath while taking readings; (14) level viscosimeter and allow to warm up before taking readings; (15) When changing speeds have motor running and hold clutch lever down; and (16) readings to be taken at all speeds, but reported at 60 r.p.m. speed only.

Calculations.—(A) Readings made on 100 scale with number one spindle. (B) Multiply reading at twelve r.p.m. by five; 30 r.p.m. by two; 60 r.p.m. by one.

Interpretation.—This viscosity test measures the viscosity of 30.0 per cent solids reconstituted spray process nonfat dry milks. Its application for baking purposes depends upon the significance of higher viscosities in a final prepared dry mix, or other bakery product. The viscosity of low heat milks will fall in the range of twelve centipoises or below. High heat milks will usually vary between 15 and 25 centipoises. High absorption high heat milks may go up to 30 centipoises or higher by this test.

There is no universal agreement among bakery technologists regarding the significance of absorption values except possibly that relatively high absorption values are good. Of greater significance in many larger bakery operations is uniformity of absorption so as to have reasonable assurance of consistent shop performance from batch to batch and from one lot of dry milk to another.

The Laboratory Bakery Test

Since it is impractical to evaluate nonfat dry milk solids in a baking test under commercial conditions, a laboratory scale baking test possibly comes the closest to approaching this goal. Commercial baking procedures vary in different plants because of differences in methods, equipment, and customer preference in different areas of the country. For this reason it is felt the ideal laboratory baking test is one that will accentuate the weakness in milk which is of greatest concern to any specific type of end use.

As a general guide for an experimental baking test, the American Dry Milk Institute (Anon. 1956) has suggested the following for the straight dough or sponge dough method.

The only equipment needed for making such experimental baking tests is the small (C-10) Hobart mixer equipped with a dough hook, a small gram scale, and two or more gallon jars or cans. The gram scale is recommended due to the fact that small amounts of some supplemental ingredients must be weighed. The experimental formula can easily be translated into the commercial size formula by substituting pounds for grams.

In making the test, it is customary to make two separate doughs as nearly alike as possible. In the experimental doughs more yeast and yeast food are used, and the doughs are usually made about one degree warmer than would be the case in commercial procedures. The following formulas and methods have been successfully employed by many bakers.

Straight Dough Formula

	Grams
Flour	600
Water (variable)	406
Yeast	15
Yeast food	3
Sugar	30
Salt	12
Shortening	24
Nonfat dry milk	36

If malt is being used, use same percentage as currently used in regular commercial-size doughs.

Method.—Mix the same as regular doughs, except about one degree warmer. Place the mixed dough in a tall-type, one gallon jar or can in fermentation room. When the dough recedes upon pressing with the fingers (about two and one half hours), scale into two pieces to make one-pound loaves. Allow about 20 minutes recovery time and then mould into loaves. Give regular proof.

Some bakers scale the loaves and pass them through the rounding machines, mark them properly and send them over the over-head proofer and through the moulding machine. They are properly labeled, placed in the proof box, and baked in the oven with regular run of bread.

Sponge Dough Formula

Sponge:	*Grams*
Flour	390
Water	230
Yeast	12
Yeast food	3

Method.—Mix at about 78° to 80°F. and allow to ferment for five hours.

Dough:	*Grams*
Flour	210
Water (variable)	175
Sugar	30
Salt	12
Shortening	24
Nonfat dry milk	36

If malt is being used, use the same percentage as currently used in regular commercial-size doughs.

Method.—Place sponge in mixer bowl and add the water. Put about half the dough flour on top of the water and then add all the other ingredients, except the shortening. Mix into a smooth batter and then add the remainder of the flour and the shortening. Mix until smooth and dry.

Mix the dough at about 80°F. Allow to rest 15 to 20 minutes. Scale into loaves. Follow the same procedure as indicated with straight doughs. Loaves may either be hand moulded or passed through the rounder and over-head proofer.

In performing the bake test any number of adjustments may be necessary to adapt conditions to any particular shop practice. Bromate levels for example, should be adjusted and the correct quantity of water for any specific powder must be used. A good quality milk powder will produce a dough which remains easy to handle throughout the baking process, and which produces a good loaf volume and quality score. For comparative purposes a known poor and good quality dry milk powder should be included in each day's test.

If these tests are carefully done, a very good indication of the baking performance of the milk will be provided.

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CHAPTER 5

John B. Woerfel

Shortenings

INTRODUCTION

Shortenings are essential ingredients of most types of bakery products. In fact, the very name is derived from their function in baking as witnessed by Webster's definition "that which shortens pastry, cake, etc.; any fat fit for such use."

As they are known to the baking industry today, a shortening may be a single fat or oil or a combination of several fats and oils. Further, it may be processed by various methods to change the characteristics of the original fats and may have emulsifiers, anti-oxidants and other ingredients added to improve and adapt it for specific purposes. Certain shortenings such as lard, butter, and some vegetable oils are sold under their common names. Products made from a mixture of fats or which have undergone rather extensive processing are usually marketed under the generic term "shortening."

Fats and oils used in shortenings are derived from both animal and vegetable sources. While a great variety of edible oils are available on the world market, only a limited number are of commercial importance in the United States. Soybean oil, cottonseed oil, lard, butter, edible beef fats, corn oil, and peanut oil—all of which are domestically produced—are the commercially important edible oils in the United States. In Table 40 is listed the amount of each of these oils produced during the past five years. Table 41 gives the usage in processed shortenings. Coconut oil and some palm kernel oil are imported and used edibly principally by the confectionery industry and in sandwich cookie fillings.

While all edible fats and oils are basically similar chemically and nutritionally, each has individual physical characteristics typical of its origin.

LARD

Over 80 per cent of the lard in the United States is produced in Federally inspected establishments. The Meat Inspection Regulations (Anon. 1957) define lard as "Fat rendered from fresh, clean, sound, fatty tissues from hogs in good health at the time of slaughter, with or without lard stearin or hydrogenated lard. The tissues do not include bones, detached skin, head skin, ears, tails, organs, windpipes, large blood vessels, scrap

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fat, skimmings, settlings, pressings and the like, and are reasonably free from muscle tissue and blood."

Lard may be rendered by any of several methods:

Prime steam lard is rendered in closed pressure tanks in direct contact with steam and is the standard lard of commerce. Action of the steam solubilizes the connective tissues and releases the fat. At the end of the rendering the contents of the tank are settled, and the fat which forms the upper layer is decanted.

TABLE 40

U. S. PRODUCTION OF EDIBLE FATS AND OILS[1]

Crop Year Beginning October 1	1954–55	1955–56	1956–57	1957–58	Est. 1958–59
	Millions of Pounds				
Vegetable					
Cottonseed	1,723	1,893	1,626	1,440	1,550
Soybean[2]	3,377	3,883	4,386	4,750	5,075
Corn oil	268	270	275	275	280
Peanut oil	20	85	107	68	140
Olive oil	3	1	6	1	5
Animal					
Lard	2,564	2,851	2,624	2,440	2,700
Butter	1,529	1,571	1,542	1,527	1,500
Other edible animal fats (principally beef fats)	280	312	312	320	330
	10,864	10,866	10,869	10,721	11,580

[1] Source: 1954–55, 1955–56 Bureau of Census, U. S. Department of Commerce.
1956–57 through 1958–59 U. S. Department of Agriculture.

[2] Includes oil equivalent of soybean exports.

Dry rendered lard is rendered in jacketed tanks with agitators. Steam heat for the rendering is applied to the jackets so that the steam does not come in direct contact with the fats. The tanks may be vented direct to the atmosphere or through vapor removal systems. The cooking which releases the fat and drives off moisture is continued until the temperature reaches approximately 240°F. and the proteinaceous residue is essentially dry. The fat is then drained off the residue, and the residue is pressed to recover additional fat.

Open kettle rendered lard is a special type of dry rendered lard in which the vessel is open to the atmosphere. Because of the resemblance to home rendering methods, the terms "farm style" or "country style" are used synonymously.

In recent years, some installations for continuously rendering (Dormitzer 1956) lard have been made. These generally depend upon comminution of the fat or mechanical rupture of the fat cells and centrifugal separation of the connective tissue and water. Heating is held to a minimum.

Certain edible hog tissues are excluded from use in lard by Meat Inspection Regulations. This was originally done to improve the quality of lard being produced. These fats are processed by the same methods as lard and sold as rendered pork fat. Rendered pork fat is used for the same purposes as lard, although it usually has a somewhat darker color and a more pronounced flavor. In other respects it may not be inferior to lard, often having better stability.

TABLE 41

SHORTENING: FATS AND OILS USED IN MANUFACTURE,[1] 1950–58

Year	Vegetable Oils					
	Soybean Oil	Cotton Seed Oil	Coconut Oil	Peanut Oil	Corn Oil	Other[2]
	Millions of Pounds					
Average						
1950	841	549	..	12	1	27
1951	731	335	20	21	1	25
1952	851	388	33	6	1	2
1953	903	376	2	4	1	4
1954	918	640	15	5	1	20
1955	930	439	4	6	3	15
1956	782	323	6	6	2	8
1957	796	272	8	6	4	3
1958[3]	1,056	239	12	5	3	2

Year	Animal Fats and Oils		Vegetable Stearin	Glycerides	Total
	Lard	Beef Fats			
	Millions of Pounds				
Average					
1950	177	31	89	..	1,727
1951	200	23	48	..	1,405
1952	232	34	66	..	1,613
1953	227	46	82	35	1,681
1954	142	89	99	39	1,969
1955	334	118	99	40	1,988
1956	459	141	90	38	1,855
1957	376	226	95	37	1,824
1958[3]	318	252	86	39	2,013

[1] Source: "The Fats and Oils Situation" FOS-196 May, 1959, Agricultural Marketing Service, U.S.D.A.
[2] Includes fish oils which have been negligible in recent years.
[3] Preliminary.

Lard has a distinctive natural flavor and odor which is considered desirable in certain baked products, principally bread, crackers, and pie crusts. The character of the flavor will vary somewhat with the rendering method, dry rendered lard having a somewhat more cooked flavor than prime steam lard due to small quantities of residual protein. Some persons have a preference for the flavor of lard rendered by one method or another, although normally no distinction is made.

When rendered from equivalent fats the color of dry rendered lard will frequently be darker than that of prime steam while the latter will be slightly higher in free fatty acids due to hydrolysis. These differences are small in properly rendered lard and lard from either process is within generally accepted limits.

Lard sold commercially to bakers and other food processors is termed refined pure lard. Refined lard may be produced by any rendering method. It is refined by a process of filtration to clarify it and remove particles of protein or other materials which might be present. The refining of lard is carried out in a plate and frame or pressure leaf type of filter employing filter aids such as diatomaceous earth or crysolite. Activated carbon or bleaching clay may be added in small quantities to improve the color, and, in some cases, the flavor.

The characteristics of lard are governed by the natural characteristics of the fat from the hogs. Variations in hardness or melting point exist dependent upon the feed which the hog received as well as climate and other conditions affecting growth. In addition, there is a wide variance of physical properties of fat from different locations on the animal. The internal fats, such as the leaf fats, are always substantially higher in melting point and lower in iodine value than the fats from the external portion of the carcass. By selection and blending of various lots of lard, the refiner controls and standardizes his product.

Special grades of lard are sometimes produced by segregating certain fats, and by special rendering methods. Pure leaf lard contains only the leaf fat which is the hardest fat on the carcass. Other grades may be made from leaf and back fats or other selections. These special lards are sometimes made by open kettle rendering and are so labelled.

Lard in the plastic state is a comparatively soft shortening. While this is ideal for some uses, there are other applications in which a firmer product is desired. For these purposes, hardened lard containing up to twelve per cent or more of completely hydrogenated lard (lard flakes) is made. By varying the amount of hydrogenated lard in the mix, any desired melting point and degree of hardness can be achieved. The amount of lard flakes required is related to the initial hardness of the lard to which it is added. Therefore, it is customary in many plants to blend flakes to certain specific physical characteristics such as congeal or melting point under laboratory control, and thus insure uniformity from batch to batch.

Table 42 gives comparative analytical data on several representative grades of lard.

TABLE 42

CHARACTERISTICS OF TYPICAL GRADES OF LARD

	Pure Refined Lard Prime Steam	Open Kettle 100 Per cent Leaf	Rendered Pork Fat	Hardened Lard
Maximum free fatty acid, per cent	.50	.25	.60	.50
Maximum Moisture, per cent	.10	.10	.10	.10
Color, Max.	10Y 1.5R	10Y 1.5R	35Y 3.5R	10Y 1.5R
Congeal P., °F.	79 to 86	88 to 91	75 to 82	95 to 100[1]
Wiley M.P., °F.	96 to 103	109 to 113	91 to 102	115 to 118[1]
O.T.M.P., °F.	89 to 96	107 to 110	86 to 97	. . .
Capillary M.P., °F.	98 to 105	113 to 117	93 to 104	118 to 122[1]
Stability (no antioxidant), Hrs., Min.	4	7	6	4

[1] Variable depending on amount of flakes added.

Uses of Lard

Lard is the most widely used shortening for bread, pies, soda crackers, and finds extensive use in pan greasing and in cookie doughs. The shortening value (the ability of a fat to lubricate and weaken the structure of a baked product) is probably unexcelled by any other plastic fat.

Bread bakers generally purchase straight refined lard, although some have a preference for special grades such as 100 per cent leaf lard, or open kettle rendered lard. There is normally no benefit in the use of a hardened lard in bread. However, in the case of continuous bread making, it has been the practice to add hydrogenated cottonseed flakes to the lard in the bakery to increase the melting point. The melting point of the fat used in this process seems to be critical to the production of a loaf with the desired characteristics. It has been found desirable to have the control of the hardness of fat at the discretion of the baker since this permits compensation for certain other variables in the process.

In addition to the shortening value of the fat, the most important characteristic of pie shortening is probably its plasticity. The quality of a pie crust is very closely related to the manner in which shortening is combined with the flour. The techniques used in preparing pie crust and the characteristics desired in the finished crust will govern the type of shortening preferred. It is also important that shortening be uniform in physical characteristics from shipment to shipment.

To fit the needs of various pie bakers, there are a number of specialized lards and pie shortenings currently being produced. Among the fats commonly used are pure refined lard, 100 per cent leaf lard, hardened refined lard and pie shortenings in which the hardening agents are meat fats other than hydrogenated lard. In addition, each of these products may be produced with natural flavor, or deodorized for those bakers who prefer a bland product.

In general, the temperature at which a pie shortening is used will be related to its hardness as well as the type of crust desired. For example, if a flaky crust is desired when using pure refined lard, a comparatively soft shortening, refrigeration of the lard and of the other ingredients is necessary. At low temperatures, it is possible to mix so that the lard is, in part at least, distributed as small discrete particles which can flatten out during the rolling to give the flaky effect.

If a short pie crust using a minimum amount of fat is desired, then the shortening and other ingredients may be mixed at much higher temperatures so that the fat is thoroughly incorporated with the flour. This practice, however, results in mealy crust although it may be desirably short and tender.

The harder pie shortenings generally permit mixing at higher temperatures. They also permit better handling of the doughs in plants where high temperatures may be encountered. Those made with harder shortenings show better cohesion and less stickiness when exposed to elevated temperatures during rolling.

Pie lards and pie shortenings may or may not be stabilized with an antioxidant. An antioxidant is not absolutely essential to pies which are distributed fresh through normal channels. However, frozen pies which may be stored for a considerable period of time normally require a shortening which contains an antioxidant.

For biscuit and cracker production, the lard used is generally straight refined lard with an antioxidant added. Hardened lard is not normally required. Since these products may have high quantities of fat, and require long shelf life after baking, an antioxidant with good carry-through, such as BHA, is essential.

For the greasing of pans, straight refined lard is frequently used. Also available from some manufacturers is lard oil, which is the portion left after the higher melting portions have been removed by a fractional crystallization process. Lard oil has the advantage of remaining liquid at room temperature and below thus simplifying its handling and application.

In addition to the use of lard as such, it has become a very important and versatile shortening raw material. Its use in processed shortenings will be discussed later in this chapter.

EDIBLE BEEF FATS

Edible beef tallow is rendered from the edible fatty tissues of cattle, by the same rendering methods as are used for lard. Beef tallow is a hard plastic fat generally having a melting point of approximately 110° to 120°F., and iodine values of from 39 to 49. Considerable variations in the physical properties of beef fat exist depending upon its origin; in this respect, it is analogous to lard. Because of its hardness, it has rather limited usage as a shortening by itself, although in some parts of the country small amounts are packed and distributed principally as a frying fat for restaurant use.

Edible beef tallow finds its principal use as an ingredient in shortening where it is combined with other softer fats. The use of beef fats in shortening was commonplace in the early years of the cottonseed oil industry where it was used as a stiffening agent in combination with vegetable oil to produce lard substitutes. With the advances of hydrogenation enabling the production of suitable plastic fats from all vegetable sources, beef tallow lost its popularity as a shortening ingredient. Without effective antioxidants, shortenings containing beef fats lacked stability and sometimes developed "tallowy" off-flavors.

However, with the use in recent years of highly effective antioxidants and improved processing methods, shortenings with excellent flavor and oxidative stability have been produced. Chang and Kummerow (1955) reported that slightly hydrogenated stabilized beef fats gave flavor stabilities better than the best commercial shortenings.

Recent studies in crystallography have indicated that beef fats tend to crystallize in the most desirable form to produce a stable shortening consistency. While edible tallow may be rather dark in color it is readily bleached to give white shortenings. As a result, beef fat has come to be recognized as a desirable shortening raw material rather than as an inexpensive substitute.

OLEO OIL, STOCK, AND STEARIN

These materials are prepared from selected beef fats by special rendering methods. Meat Inspection Regulations (Anon. 1957) specify that to bear this designation, the fats must not be rendered at temperatures above 170°F.

Traditionally the fats were chilled overnight in water at 40°F., hashed, rendered in open kettles with hot water jackets, settled, the fat decanted and pumped to clarifier tanks, and again settled. In recent years, the process has been replaced by centrifugal rendering methods which cut the total time from 48 hours to a few minutes and drastically reduce the space required.

The rendered fat is known as oleo stock. Oleo stock has essentially the same physical characteristics as edible tallow. However, it is generally lower in free fatty acid, and has a mild characteristic flavor, sometimes described as "nut-like" or "butter-like." It varies in color from a pale to a strong yellow depending on the pigmentation of the original beef fats.

Almost all oleo stock is further processed by fractional crystallization at temperatures of 92° to 95°F., to yield oleo oil and oleo stearin in the proportion of about two-thirds oil to one-third stearin.

In the separation, the color and flavor is mostly retained by the oil which is somewhat more pronounced in flavor and yellow color than the stock from which it is made.

Oleo stearin is a hard waxy solid having a melting point of approximately 120° to 125°F., and an iodine value of about 20 to 25. It is principally used as an ingredient in shortenings. It is particularly valued as an ingredient in puff paste shortenings where a tough waxy consistency is desired.

Oleo oil is stabilized with antioxidants and plasticized into drums or cans. Considerable quantities are also sold in bulk in tank trucks.

TABLE 43

TYPICAL ANALYSES OF OLEO PRODUCTS

	Stock	Oil	Stearin
Free fatty acid, per cent	0.30	0.35	0.20
Color	20Y 2.0R	20Y 2.5R	12Y 1.0R
Titre, °F.	113	108	122
Wiley M.P., °F.	117	97	122
Stability AOM without antioxidant	12	6	20

Oleo oil normally has a melting point of approximately 95°F. It has the shortest plastic range of all domestic fats although not as short as the lauric acid fats such as coconut oil. Plastic oleo is workable generally in the range of 70° to 80°F.; above 80°F. it softens rapidly, becoming completely liquid at body temperature. For extreme hot weather use some manufacturers make summer formulas containing some stearin to raise the melting point and extend the plastic range to temperatures above 80°F.

A shortening with a very white color and bland flavor, but retaining the short plastic range is produced from oleo oil for those uses where a bland flavor and white color are desired.

In baking, oleo oil is principally used in cookies. It is used in both doughs and sandwich fillings. In the doughs, it has excellent stability and shortening value, and has better creaming ability than lard making it adaptable to such products as vanilla wafers. The natural flavor and low melting point are considered desirable by manufacturers for their contribution to flavor and eating quality. In sandwich fillings, the deodorized product is generally preferred. Here the short plastic range and low melting point are highly desirable characteristics.

BUTTER

Butter is considered to be the best of all baking shortenings from a flavor standpoint. The flavor of butter is esteemed by most individuals and possesses the quality of persistence so that it carries through the baking and imparts its desirable flavor and aroma to the finished baked product.

The United States standards for Grades of Butter (Anon. 1954) define it as follows:

> "**Butter.**—Butter is the food product made from milk or cream, or both, with or without common salt or additional coloring matter, and containing not less than 80 per cent by weight of milk fat, all tolerance having been allowed for."
>
> **Cream.**—The term "Cream" when used in this subpart means cream separated from milk produced by healthy cows. The cream shall be pasteurized at a temperature of not less than 165 F. and held continuously at such temperature for at least 30 minutes; or by any other method of pasteurization which gives equivalent results in the destruction of the phosphatase enzyme."

Butter is classified according to the following grades:

U. S. Grade AA or U. S. 93 Score
U. S. Grade A or U. S. 92 Score
U. S. Grade B or U. S. 90 Score
U. S. Grade C or U. S. 89 Score

In determining the grade of butter it is first classified for flavor according to intensity and type of a large number of specified flavors. It is then judged for defects in body, color and salt according to definite schedules and the grade adjusted downward if the defects exceed a specified total. It is apparent that under this system the highest grade will be the most uniform. The lower grades will be somewhat more variable and it is not known from the grade what specific defect or defects contributed to it.

In the past many bakers have preferred low score butter because of price, and with the belief that the stronger flavors often associated with low score were actually more effective in flavoring baked goods. Today it is noted that many bakers who stress their use of butter in their products use only the highest grades.

The creaming quality of butter is rather poor. Cakes made with butter are generally lower in volume and have a coarser grain than those made with a high quality shortening with good creaming characteristics. For this reason some bakers use part butter in the formulas for the flavor it contributes and part shortening for increased volume and finer grain. Butter is widely used for specialty breads, sweet goods, cookies and pastries; it has good shortening value and is very suitable for Danish and other roll-in doughs.

Butter is a perishable commodity and subject to certain types of deterioration not encountered with other fats, except margarine. With other fat atmospheric oxidation is the most serious cause of deterioration, while bacterial and mold action are important in deterioration of butter. Salt has a preservative action but since it is incorporated in the separated butter it may not be evenly distributed, leaving some small droplets of water in which bacterial action can take place.

Oxidative deterioration of butter results in a "tallowy" flavor. This appears with very slight oxidation, in some cases with a barely detectable concentration of peroxides.

When held at low temperatures butter deteriorates very little and may be stored for months without significant loss of flavor or vitamin A content.

PRODUCTION AND REFINING OF VEGETABLE OILS

Vegetable oils of all types are obtained from the oil bearing seed by either expelling the oil with screw presses or extracting it with solvents. Crude oils must undergo extensive processing to make them suitable for edible use.

Trading in crude vegetable oils is done under rather specific rules (Anon. 1958A and Anon. 1958B) which provide for discounts or premiums over the nominal price for oil of poorer or better quality than the standard. The principal point of quality involved is that of "refining loss." Refining loss is the weight loss obtained in refining the oil using sodium hydroxide under certain closely specified laboratory conditions. Refining loss is an important criterion for determining the value of an oil to the processor since alkali refining is the first step in the processing of all vegetable oils for edible use.

In refining crude oils, the free fatty acid is neutralized by the addition of an alkali such as sodium hydroxide or soda ash. Reaction of alkali with the free fatty acid forms a soap which is separated along with certain other constituents, such as gums, by centrifuging. The refined oil is then water washed to remove any residual soap and vacuum dried before pumping into storage for further processing. The processing which refined oils receive in the production of hydrogenated shortenings will be described later in this chapter.

Salad and Cooking Oils

Considerable quantities of vegetable oils are marketed in the United States as salad and cooking oils. A salad oil is basically an oil which will remain essentially liquid at refrigerator temperatures of 40° to 45°F., and will produce a mayonnaise emulsion which is stable at low temperatures. Labeling an oil, "cooking oil," implies that the oil will not withstand low temperatures without congealing. Salad oils are used commercially in the United States for making various types of bakery goods such as chiffon cakes, and in the preparation of doughnut mixes. Cooking oils are principally used for frying.

Vegetable oils when sold as salad or cooking oils are always labelled with the name of the oil or oils used in their preparation. This is in contrast to the labeling of hydrogenated shortenings where the declaration "hydrogenated vegetable oils" is all that is required.

Soybean oil and corn oil are natural "winter" oils or salad oils. To produce a salad oil from these, they need only be refined and deodorized.

In order to produce a salad oil from cottonseed oil, it must be subjected to winterization. This process consists of cooling the oil to low temperatures to solidify the higher melting portion or "stearin oil." The solidified portions, which amount to approximately 20 to 25 per cent of the total oil, are then removed by filtration. The salad oil is then bleached and deodorized. The higher melting portion of stearin oil resulting from this process is used in hydrogenated shortening or margarine. Most of the cottonseed oil sold as oil is winterized to a salad oil. However, some cottonseed oil is simply refined and deodorized and sold as a cooking oil.

Peanut oil is refined and deodorized for sale as a cooking oil. It is occasionally used as an ingredient in hydrogenated shortenings.

Soybean salad oil generally exhibits some tendency to revert in flavor. By this is meant that after deodorization, certain typical flavors tend to return. For this reason, the use of liquid soybean oil for certain purposes, and particularly for frying, is limited. Peanut oil, cottonseed cooking and salad oil, and corn oil all are widely used for deep fat frying.

In addition to their use as oils, soybean and cottonseed oils are important raw materials for plastic shortenings. Cottonseed oil was traditionally the principal raw material for hydrogenated vegetable shortening. With the rapid growth of the soybean industry in the past two decades, soybean oil has found increasing usage until today several times as much soybean as cottonseed is being used.

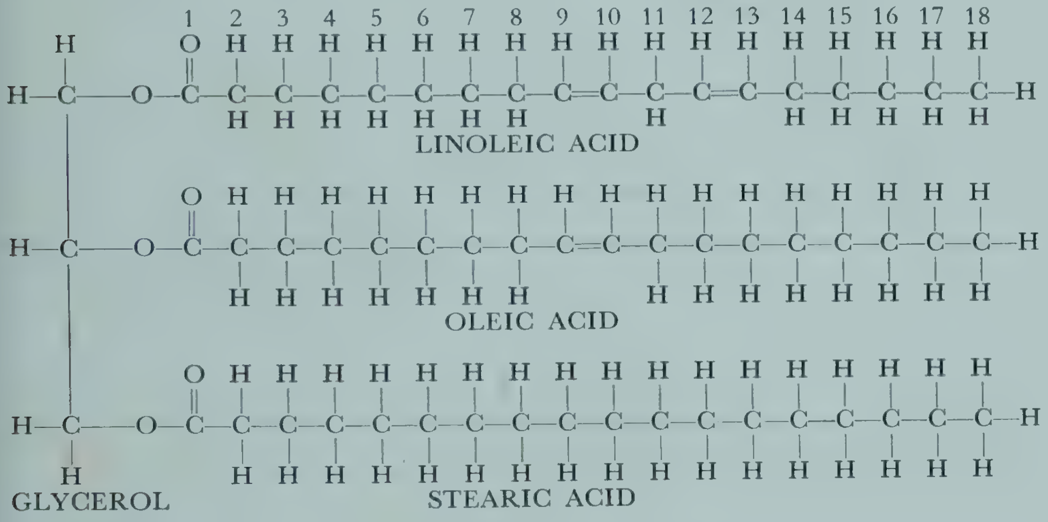
Some considerable prejudice against soybean oil shortening has existed because of lack of flavor stability associated with these products in past years. With improved technology at all stages including extraction of the oil, bleaching, hydrogenation and deodorization this problem has been largely overcome. Today premium quality shortenings sold for the most exacting uses contain major proportions of soybean oil.

Processing Shortening

The shortenings previously described in this chapter are those which are sold under their common name. They have received little or no processing to change their inherent physical properties. In each case, they are ideally suited for certain purposes; however, they do have certain limitations and can be improved for other functions by modification.

In processing shortening, certain chemical and physical changes are brought about under close control to achieve the physical properties desired in finished material. To understand some of these changes a short discussion of the chemistry of fats and oils may be of interest.

Fats and oils are glyceryl esters of fatty acids. Predominantly they are triglycerides having three fatty acids attached to the glycerol. If the acids are the same, it is a simple triglyceride. If two or three different fatty acids are present, it is a mixed triglyceride. The structural formula of a typical mixed triglyceride is shown below:



β-OLEOLINOLEOSTEARIN

The fatty acids are straight chain aliphatic acids with a single carboxyl group. In natural fats, the fatty acids are almost all those with even numbers of carbon atoms, and may vary in chain length from 4 to 26 carbon atoms. The melting point increases with chain length, and those with 12 or more carbon atoms are solids at ordinary temperatures.

Fatty acids may further be classified as saturated or unsaturated. Saturated acids are those containing only single bond carbon linkages. Unsaturated fatty acids contain one or more double bond linkages. The illustration above shows the formulas of oleic acid and linoleic acid which are the two very common unsaturated acids found in natural fats. It will be noted from the structural formula that those carbon atoms at the double bonds have only one hydrogen atom attached and are thus "unsaturated" with respect to hydrogen. The melting point of the fatty acid and of triglycerides decreases rapidly with the degree of unsaturation.

The physical properties of the triglyceride are influenced by the fatty acids which it contains, and also by the position of the different fatty acids on the glycerol molecule. Each natural fat contains a variety of fatty acids, and an even greater variety of triglycerides depending on the position of various fatty acids. The properties of the fat will be governed by the type and relative amounts of triglycerides present.

The total number of different triglycerides present in a fat is relatively large. With as few as four different fatty acids, there are possible 40 different triglycerides. With additional fatty acids a great many more may be present in a fat. The typical fatty acid composition of various fats is listed in Table 44.

Table 44

TYPICAL FATTY ACID COMPOSITION OF VARIOUS NATURAL FATS AND OILS

		Vegetable Oils					Animal Fats		
Fatty Acid (Common Name)	Chemical Formula	Coconut	Corn[1]	Cottonseed	Peanut	Soybean	Butter[2]	Lard	Tallow
Saturated Acids									
Butyric	$C_4H_8O_2$	...	...	...	...	...	3.7		
Caproic	$C_6H_{12}O_2$	.5	...	...	...	...	1.7		
Caprylic	$C_8H_{16}O_2$	8.0	...	...	...	...	1.0		
Capric	$C_{10}H_{20}O_2$	7.0	...	...	...	...	1.9	...	...
Lauric	$C_{12}H_{24}O_2$	48.0	...	...	...	...	2.8	...	0.1
Myristic	$C_{14}H_{28}O_2$	17.0	0.1	0.5	...	0.1	8.1	1.0	3.0
Palmitic	$C_{16}H_{32}O_2$	9.0	8.1	21.0	7.0	8.0	25.9	28.0	29.0
Stearic	$C_{18}H_{36}O_2$	2.0	2.5	2.0	4.0	4.0	11.2	13.0	20.0
Arachidic	$C_{20}H_{40}O_2$	...	...	0.2	3.0	0.6	1.2	...	0.8
Behenic	$C_{22}H_{44}O_2$	...	...	...	2.0				
Lignoceric	$C_{24}H_{48}O_2$	...	...	0.3	2.0				
Unsaturated Acids									
Myristoleic	$C_{14}H_{26}O_2$	...	...	...	...	0.1	0.6	0.2	0.5
Palmitoleic	$C_{16}H_{30}O_2$	0.2	1.2	...	...	0.2	3.4	3.0	2.0
Oleic	$C_{18}H_{34}O_2$	6.0	30.1	29.0	60.0	28.0	32.8	46.0	42.0
Linoleic	$C_{18}H_{32}O_2$	2.0	56.3	45.0	22.0	54.0	3.7	6.0	2.0
Linolenic	$C_{18}H_{30}O_2$	...	...	2.0	...	5.0	...	0.7	0.5
$C_{20}H_{22}$ Unsaturated	...	...	1.7	...	...	...	1.7	...	0.1

[1] Baur and Brown (1945).
[2] Hilditch and Jasperson (1941).

The properties of the fat will be governed by the particular components and the relative amount of each. Individual triglycerides vary greatly in their physical properties, for example, melting points may be above 150 F. or below 0 F. If a fat contains a high percentage of the higher melting components it will be solid at ordinary temperatures, if low melting components predominate the fat will be liquid or, as commonly termed, an oil.

While each single pure triglyceride will have a definite melting point, plastic fats consist of a variety of triglycerides of various melting points so that solid and liquid phases co-exist. The hardness of the fat is related to the proportion of solids, although other factors such as crystal form are also involved. As temperature increases more of the triglycerides melt and the fat softens. Fats consisting largely of intermediate melting components soften rapidly with increasing temperature in the range where these components melt and have a comparatively "sharp" melting point and short plastic range. In fats consisting mainly of a combination of very low melting and very high melting triglycerides the amount of the solid portion and the hardness does not change as much with a temperature change and these fats are said to have a long plastic range.

Two chemical methods for modifying fats are used commercially in shortening production—hydrogenation and interesterification.

Hydrogenation.—Hydrogenation is the addition of hydrogen at the double bonds in the fatty acid chain. Polyunsaturated acids are reduced to monounsaturated and monounsaturated acids to saturated. Simultaneously with the addition of hydrogen, other reactions take place: (1) the double bonds migrate along the fatty acid chain, forming positional isomers; and (2) the unsaturated fatty acids, which in natural fats (with a few exceptions) exist in the cis form, may be converted to the trans form of geometrical isomer. In polyunsaturated acids, each double bond may exist in either the cis or trans configuration; thus making possible several isomers. The physical properties of each isomer differ from those of the others.

In the practical art of hydrogenation, the conditions of hydrogenation are controlled to govern the course of the reactions to achieve certain specific properties in the end product. These properties are governed by the selectivity of the hydrogenation, as well as the degree of formation of positional and geometrical isomers. A selective hydrogenation is one in which all of the polyunsaturated acids are reduced to monounsaturated acids before any appreciable amount of the monounsaturated acids are reduced to saturated acids.

Commercial hydrogenation is carried out in pressure vessels equipped with agitators and means for cooling and heating. A finely divided nickel catalyst is suspended in the oil. The oil is heated to desired temperature and hydrogen under pressure admitted. Temperatures are usually in the range of 250 to 450°F., and pressures from 0 to 100 psig. The reaction is exothermic and cooling is required to control the temperature.

The factors affecting hydrogenation are: (1) purity of hydrogen, (2) purity of oil; (3) agitation; (4) type of catalyst; (5) temperature, and (6) pressure and/or rate of admission of hydrogen gas.

The first three factors are kept essentially constant in a commercial operation. Control of the hydrogenation is effected by varying the last three factors.

Fats and oils may be hydrogenated to complete virtual saturation to produce stearin or "flakes." The characteristics of stearin are the same regardless of the conditions of hydrogenation, so conditions are generally chosen to complete the reaction in the shortest time.

In the past, large quantities of standard shortening were produced by blending approximately 12 to 15 per cent of stearin with an unhydrogenated oil. This type of shortening is still produced today, but it is common practice to hydrogenate slightly all of the oil to give it added oxidative stability.

In making "all-hydrogenated" shortenings, the stock is hydrogenated under carefully controlled conditions to a selected end-point. Two or more stocks may be hydrogenated to different degrees and blended to give even greater control of the characteristics of the finished shortenings.

In general, the purposes of hydrogenation are to: (1) produce semisolid shortenings from liquid oils; and (2) to increase the resistance of the fat to oxidative rancidity.

Oxidation of the fat takes place by reaction of oxygen, at the double bonds. The polyunsaturated acids are more readily oxidized than are the monounsaturated acids; therefore, where maximum stability is desired, highly selective hydrogenation conditions are chosen. By reducing the unsaturation of a fat, its susceptibility to oxidation is reduced. However, other factors also affect oxidation so saturation alone is not a measure of stability.

While hydrogenation was originally practiced primarily on vegetable oils, it is today commonly used in processing meat fats. Since meat fats are already semisolids, the degree of hydrogenation possible is limited and the purpose is primarily to increase stability. On lard, the iodine value reduction usually will not exceed 10 to 12 points. A reduction of as little as 2 to 3 points has a marked effect on the oxidative and flavor stability of meat fats.

Interesterification.—While interesterification or molecular rearrangement can be carried out on any fat or oil, it is primarily of commercial value in the processing of lard. As pointed out earlier in this chapter, lard is a widely used and preferred shortening for numerous uses, but it has not been widely acceptable as a shortening for cakes, icings and similar uses where creaming ability is important. Some improvement in the creaming ability of lard is affected by hardening it with lard flakes or by hydrogenation, and in these forms some usage has been made in baking cakes. However, this type of lard product is not universally acceptable for this purpose.

The unique physical properties of lard are believed to be related to a specific triglyceride structure. Examination of the triglycerides present in lard reveals that in the mixed triglycerides of lard (that is those containing both saturated and unsaturated fatty acids) the unsaturated acids are predominately in the one and three positions and the saturated in the two position (Reiser and Reddy 1959).

The random re-arrangement reaction (Slater 1953; Vander Wal and Van Akkeren 1951) is carried out on vacuum-dried lard under the influence of a catalyst, commonly sodium methoxide. During the reaction, the fatty acid groups are constantly interchanged within and among the glyceryl residues. After a sufficient time, the catalyst is inactivated with water, thus stopping the reaction. The soap resulting from the catalyst is removed by centrifuging and water washing. Steam deodorization removes residual methyl esters as well as making the product odorless and tasteless.

The resulting rearranged lard has physical characteristics quite different from the original lard as measured by such tests as melting point, cooling curve, and dilatometry. Examination of the glycerides of the rearranged lard reveals more nearly random distribution of the various acids present.

Luddy *et al.* (1955) determined the proportions of the four glyceride types before and after rearrangement and these results are shown in Table 45.

Table 45

PROPORTIONS OF GLYCERIDE TYPES IN LARD

	GS_3	GS_2U	GSU_2	GU_3
Untreated	2.9	25.3	53.3	18.5
Rearranged	4.3	27.3	45.5	22.9
Random	5.3	26.5	43.9	24.3

Note: In the above notation, "G" stands for glycerol and "S" and "U" for saturated and unsaturated fatty acids respectively.

The close agreement between the values for rearranged lard and the calculated values for random distribution should be noted. It is reasonable to assume that there is also a random distribution of the positional isomers of the mixed glycerides.

Rearranged lard from this process is too soft for general use as a plastic shortening; therefore, it is the usual practice to blend a percentage of completely hydrogenated meat fats or vegetable oils or to hydrogenate slightly the entire mass to obtain and control desired plastic character.

A second process of lard rearrangement called directed rearrangement (Hawley and Holman 1956) is also used. In this process, the catalyst is sodium-potassium alloy (NaK) and the reaction is carried out at temperatures below the melting point of the fat. At these temperatures, tri-saturates precipitate as they are formed by the reaction. As the one reaction product is removed, the liquid phase reaction continues to seek equilibrium. When a sufficient amount of tri-saturates are formed, the catalyst is inactivated with CO_2 and water, and the soap removed in much the same manner as for random rearrangement. The resultant product is hydrogenated slightly to improve its plastic range and processed by conventional methods into a satisfactory shortening for cakes and icings.

Deodorization.—Butter, lard and oleo oil are the only shortenings marketed in the U. S. which are naturally flavored.

All of the other shortenings and oils and including much lard are deodorized to produce a bland or flavorless product. Vegetable oils all possess undesirable flavors in their raw state, and many fats which are treated with bleaching clays or by hydrogenation, acquire unpleasant flavors which must be removed. Rearranged lard must be deodorized to remove residual methyl esters.

Deodorization is essentially a steam distillation, and may be accomplished by batch, semi-continuous, or continuous methods. Whatever the process the essential feature is the contacting of the oil at high temperatures (up to 475 F.) with steam and removal of the steam and volatiles by high vacuum. The vacuum used in modern equipment is as low as 1 to 2 mm. Hg absolute. Complete absence of air is essential to effective deodorization, and sensitive leak detection equipment is routinely used to insure complete tightness of the equipment.

Deodorization reduces the free fatty acid to very low levels usually less than .05 per cent as oleic. Peroxide values are reduced to nearly "0." The volatile flavor and odor elements are essentially completely removed. Considerable bleaching also occurs.

The best test for measuring the effectiveness of deodorization is flavor. While absolute blandness is the aim, there is always a very slight residual flavor and odor. Flavor grading of oils has been developed to a fine art and skilled operators frequently identify operational difficulties by characteristic flavors in the oil.

Bleaching.—A white appearance is preferred in most shortenings. Some bleaching of oils takes place during hydrogenation and deodorization. However, most shortenings are subjected to a specific bleaching step. Bleaching is accomplished by adding a bleaching clay to the heated oil and filtering through a suitable filter press. A variety of clays are available, some of which are natural bleaching earths, and some are prepared by activating the earth with acids. Activated charcoal is also used at times in combination with the clay.

The type of absorbent which is used will be governed by the type of oil being bleached, and the economic factors of the amount of clay required and the oil retention of the spent clay. Shortening manufacturers may use more than one type of clay and switch from one to another, depending on the stocks being bleached.

Plasticizing and Tempering.—The final step in the production of shortening is the plasticizing and tempering. These steps are of importance in achieving the proper consistency and performance characteristics in the finished plastic shortening. Plastic shortenings have been shown by Bailey (1951) to consist of small needle-like crystals enclosing liquid oil. In the crystallization, the finest possible crystal structure is desired, to achieve smooth appearance, and firm consistency. This is best accomplished by rapid chilling.

While in the past, several devices for chilling have been used, today the closed continuous internal chiller is used almost exclusively. This consists of an externally refrigerated cylinder or "A" unit through which the fat is pumped. This cylinder is equipped with revolving scraper blades which are pressed lightly against the cylinder walls by the resistance of the fat. These scrapers prevent the formation of a layer of fat on the refrigerated surface, and maintain high heat transfer efficiency. In the "A" unit, the temperature of the fat drops from about 115° or 120°F., to between 55° and 70°F., depending on the type of fat.

After chilling, the shortening passes to another cylinder or "B" unit where it is maintained in constant agitation by means of a rotating shaft fitted with a series of fingers which intermesh with stationary fingers on the shell. This cylinder is neither heated nor cooled, but during the passage the product temperature will rise several degrees due to the evolution of heat of crystallization. If the product is filled directly from the "A" unit, it will be of poor texture and excessively hard. On the other hand, excessive retention time in the "B" unit can result in a product which is too soft. Many installations are equipped with multiple "B" units and the number used can be varied with requirements for a particular product.

Air is usually introduced into the chilling unit along with the shortening. In lard, this is usually 6 to 8 per cent by volume, and in shortening 10 to 15 per cent. During the chilling process, this air is thoroughly incorporated into and remains in the plastic shortening in the form of minute bubbles. These contribute a white, opaque, creamy appearance. The product is normally under high pressures in both the "A" and "B" units. Immediately before going into the package, it passes through an expansion valve. This rapid expansion improves the sheen and appearance of the product.

After the packages are filled, they are held at temperatures of 80° to 85° F., for approximately 48 to 72 hours to "temper" the shortening. The temperature of the product rises several degrees indicating that further development or change in form of the crystals is taking place. This tempering period is important to the development of optimum creaming and consistency. In a recent test on all-purpose hydrogenated vegetable shortening, the differences in penetration and pound cake volume shown in Table 46 were found in samples held at 70° F. for varying times after filling.

TABLE 46

EFFECT OF HOLDING TEMPERATURE ON CONSISTENCY AND POUND CAKE VOLUME OF A HYDROGENATED VEGETABLE SHORTENING

Holding Period	Temperature	ASTM Penetration[1]	Pound Cake Volume, Ml.[1]
96 hours	70°F.	138	230
48 hours	70°F.	149	268
Specification for comparison		135–155	250 Min.

[1] In these tests it would be expected that replicate samples would agree within 5 points on penetration and 10 points on cake volume.

Storage of Shortening

Most manufacturers recommend that shortenings, particularly those intended for uses where creaming is important, be held at 70° to 80° F. Observance of these conditions is important if maximum performance is desired. At low temperatures shortenings become hard and brittle and difficult to work. At high temperatures they become excessively soft and show impaired creaming quality. In addition to these obvious effects, shortenings exposed to high temperatures show permanently impaired creaming properties even when brought back to normal room temperatures. In extreme cases of high temperature storage the physical appearance of the shortening will be changed and appear dark and "Vaseline like." The changes are believed to be due to changes in the crystal form of the solid portions of the fat which are promoted by the high temperature and temperature change. As might be expected, shortenings with high solids at the higher temperatures appear to resist these changes best.

Properly tempered shortening exposed to cold temperatures will usually temper back to 70° to 80°F. without permanent impairment of its performance or its appearance. Raising the temperature of shortening from 40° or 45°F to 70°F. may require a week or more for drums.

Shortenings should not be stored near odorous materials. Fats are prone to absorb many foreign odors which are undesirable in the shortening.

Antioxidants

Lard and beef fats in their natural state are considerably less stable to oxidative rancidity than hydrogenated vegetable oils of the same degree of saturation. This phenomenon is due to the presence of certain natural antioxidants in vegetable oils. Over the years a great deal of research effort was directed at finding effective antioxidants which would make meat fats sufficiently stable for those applications requiring high stability fats. Many substances were investigated and within the last two decades a number of substances have been developed which are highly satisfactory.

The Meat Inspection Regulations (Anon. 1957) specify the antioxidants which may be used in meat fat shortenings and maximum levels. When antioxidants are used in accordance with these regulations the shortening must be labelled "Oxidation inhibitor added to improve stability" or "Oxygen interceptor added to retard rancidity." The following antioxidants are permitted at the levels indicated:

	Per cent
Resin guaiar	0.10
Nordihydroguaiaretic Acid (NDGA)	0.01
Tocopherols	0.03
Butylated hydroxyanisole (BHA)	0.01
Butylated hydroxytoluene (BHT)	0.01
Propyl gallate	0.01

If two or more of the antioxidants BHT, BHA, NDGA or propyl gallate are used, the total may not exceed 0.02 per cent.

In addition to these antioxidants .01 per cent of citric acid and/or phosphoric acid and/or monoisopropyl citrate may be used. These materials, although not antioxidants, are synergists which enhance the effect of the antioxidants. Since these materials are all chelating agents it is believed that their synergistic effect is related to the scavenging of metals.

While all of the above antioxidants are effective, they are by no means equivalent. BHT and BHA and to a lesser extent NDGA and resin guaiar have a carry through effect in stabilizing the finished baked goods. Propyl gallate has no carry through effect although it is very effective in stabilizing the fat.

Some of these antioxidants exhibit color effects under certain conditions. Propyl gallate in the presence of moisture and iron shows a deep blue coloration. NDGA and propyl gallate may show green discolorations when mixed with egg yolk. Resin guaiar is also reported to show color reactions under certain conditions.

It is common practice to utilize a combination of antioxidants and acidic synergists. These combinations are chosen to achieve optimum results for particular types of shortenings.

Table 47 illustrates the stabilizing effect of BHA and propyl gallate on lard and the synergistic effect of citric acid, as well as the carry through effect of BHA in crackers and pastry.

TABLE 47

EFFECT OF ANTIOXIDANTS ON STABILITY OF LARD AND BAKED PRODUCTS[1]

Antioxidant, Per cent	Average AOM Stability, Hrs.	Carry Through Effectiveness Schaal Oven	
		Cracker, Days	Pastry, Days
None	4.6 (9)	143	20
.01 BHA	20.4 (7)	556	278
.01 BHA .002 Citric acid	26.4 (4)	452	291
.01 BHA .002 Citric acid .003 Propyl gallate	57.8 (7)	--	-

(X) = Number of lard samples.

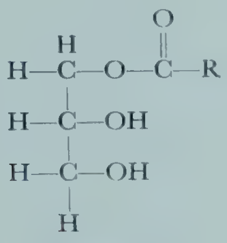
[1] Dungan *et al.* (1951).

Emulsifiers

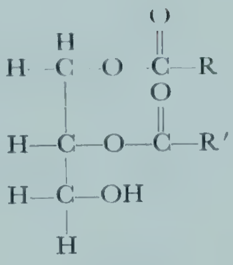
Emulsifiers are widely used as ingredients in shortening for cakes, icings and bread. Monoglycerides and diglycerides of fatty acids and of certain other organic acids are by far the most widely used. Not only are these used as ingredients of shortening, but to a large extent bakers purchase the monoglyceride separately and add it with the shortening, particularly for bread use. Usage of these emulsifiers in shortening has been in the range of 35 to 40 million pounds annually for the past several years or approximately two per cent of the total shortening produced.

Mono and diglycerides are similar chemically to triglycerides except that only one or two fatty acids are associated with each glycerol molecule.

The structural formulas are as follows:



Monoglyceride



Diglyceride

The symbol R represents the carbon chain of the fatty acid.

The OH groups are hydrophilic while the fatty acid group is lipophilic, accounting for the surface active properties. Mono- and diglycerides are formed by the partial hydrolysis of triglycerides, and are formed from triglycerides in the digestive tract during the metabolism of fats. Monoglycerides are also found normally in all fats and oils at levels of a few tenths of one per cent. Since they are considered natural ingredients of food fats and are metabolized in the same manner as triglycerides in the body, there is no objection to their use in food.

Monoglycerides are functionally many times more effective than diglycerides and the monoglyceride content is considered the significant measure of activity, although the most common commercial preparation contains approximately equal quantities of the two. Evidence has been presented that under certain circumstances the diglyceride content may have either a slightly beneficial or a slightly detrimental effect.

Commercially, monoglycerides are prepared by the reaction of a normal fat with an excess of glycerol using an alkaline catalyst. The reaction is carried out at elevated temperatures under an inert gas. The reaction, which is an interesterification, proceeds to equilibrium. The final product is a mixture of mono-, di-, and triglycerides. The composition of the equilibrium mixture is determined by the ratio of glycerin to fat and the conditions of the reaction. Mixtures with 40 to 45 per cent alpha-monoglycerides are the most common, although mixtures containing 52 to 56 per cent alpha-monoglycerides are also manufactured.

Although some authorities have stated that manufactured monoglycerides contain only alpha-monoglycerides, it now appears that these manufactured products contain substantial quantities of beta-monoglycerides (Brokaw *et al.* 1955).

Products containing 90 per cent monoglyceride are made by molecular distillation, and are also available.

The function of the monoglyceride in each particular use is related to the degree of saturation of the fat from which it is made and to the fatty acid chain length. Those most commonly used are made from cottonseed oil, lard, partially or completely hydrogenated cottonseed oil, and completely hydrogenated lard or tallow.

Physically the various monoglycerides resemble in a general way the fat from which they are made. When incorporated in shortening the saturated ones exhibit a hardening effect similar to tristearin while the unsaturated ones have a softening effect. Physical as well as functional factors must be considered in formulating a shortening for a given purpose.

In recent years a type of mono- and diglyceride containing lactic acid in addition to fatty acids has been used to some extent. These are generally made by direct esterification of fatty acids, lactic acid and glycerin. These emulsifiers, sometimes called lactylated emulsifiers, have been used for shortenings designed primarily for cakes. They have excellent ability to whip and incorporate air into cake batters under certain specific conditions of formulation.

Lecithin is used as an emulsifier in some specialty shortenings to a limited extent. Its use is usually in conjunction with other emulsifiers rather than by itself.

Polyoxyethylene sorbitan monostearate has been used as an emulsifier in specialty shortenings for cake icings and fillings. It appears to be quite effective in stabilizing the emulsion and reducing weeping in fillings containing high percentages of water.

TYPES OF SHORTENINGS

Shortenings may be classified either by the raw materials from which they are made or by the use for which they are intended. In the past the former method of classification was quite widely used and pure vegetable shortenings were considered to have functional properties for certain uses not attainable with meat fats. In recent years, the use of rearrangement, antioxidants and other technological advances have made possible production of shortenings from various raw materials which are functionally equivalent. Currently most manufacturers make parallel lines of shortenings from vegetable oils and from meat fats. For each functional type these are interchangeable so that many bakers approve and use either type, interchangeably, with price being the deciding factor.

Functionally, shortenings may be divided into three major classifications, although in recent years there has been an increasing number of specialty shortenings designed for optimum performance in one specific use.

There are certain properties that are considered desirable and sought in all processed shortenings: (1) bland flavor; (2) white appearance; (3) good plasticity; and (4) flavor and oxidative stability.

TABLE 48

COMPARATIVE ANALYSES AND PERFORMANCE DATA OF ALL PURPOSE HYDROGENATED VEGETABLE OIL SHORTENINGS AND MEAT FAT SHORTENINGS

	Free Fatty Acid, Per cent	Color R	I.V.	Wiley M.P., °F.	Stability AOM, Hrs.	ASTM Penetration mm. × 10		Solids Fraction			Index, 104°F.	Pound Cake Volume, CC/100 gm.
						70°F.	92°F.	50°F.	70°F.	92°F.		
Hydrogenated Vegetable												
Brand A	.05	1.5	73.0	111.2	141	155	222	35.1	21.9	11.5	9.8	263
B	.02	1.2	78.0	117.5	80	165	203	29.9	21.2	14.5	9.4	252
C	.03	1.1	72.4	114.6	98	163	213	27.8	21.7	14.4	8.3	281
D	.02	1.0	73.7	117.0	83	165	190	26.1	22.0	14.6	9.3	227
E	.05	1.1	73.1	113.0	106	173	224	28.7	18.2	10.5	5.8	278
Average	.03	1.2	74.0	114.6	102	164	210	29.5	21.0	13.1	8.5	260
Meat Fat												
Brand A	.03	1.2	55.8	115.5	95	187	200	31.8	22.5	16.5	10.9	263
B	.06	1.4	59.8	119.5	110	158	183	30.0	24.2	19.0	13.5	273
C	.04	1.1	60.9	116.2	92	175	211	31.6	25.2	18.4	12.2	261
D	.04	0.9	61.0	115.1	57	156	183	29.2	23.8	18.1	12.3	272
E	.03	1.1	59.4	119.3	74	186	206	29.9	23.4	18.7	13.8	252
Average	.04	1.1	59.4	117.1	86	172	197	30.5	23.8	18.1	12.5	264

The relative importance of the last two factors will differ with shortenings for different uses.

All Purpose Shortenings

As the name implies these are used for many different bakery uses. In this type of shortening emphasis is on good plasticity and creaming qualities. While stability is relatively high, extremely high stabilities are not sought at the expense of plasticity. In producing these shortenings, the bulk of the fat is processed by hydrogenation and blending to a somewhat softer consistency than finally desired, and then 4 to 12 per cent of completely hydrogenated fat is added to achieve the plasticity and plastic range.

Several types of all purpose shortening are manufactured. All hydrogenated and rearranged lard types are generally considered the best functionally and are sold as premium products. Analytical and performance characteristics determined on samples of several widely sold brands are given in Table 48.

Standard shortenings made both from meat fats and from vegetable oils are also manufactured and sold at somewhat lower prices than the premium shortenings from the same raw materials. Pure vegetable standard shortening, which is identified by the labelling "Made from hardened vegetable oils" consists of very slightly hydrogenated or unhydrogenated oils hardened with a considerable percentage of stearin. They are generally slightly inferior to the all hydrogenated product in stability and creaming qualities although they do have excellent plastic range.

Blended standard shortening is made from meat fats and vegetable fats or from meat fats only. Edible tallow, unrearranged lard, and vegetable oils are used as the raw materials. Characteristics are controlled primarily by blending of the fats. Some of the raw materials may be hydrogenated. Vegetable oils are almost always hydrogenated at least to a slight degree.

High Absorption Shortenings

These are made specifically for cake and icing work and contain added emulsifiers. Most commonly the emulsifier is of the mono- and diglyceride type. These shortenings make possible the use of increased proportions of moisture and sugar, and produce cakes which are sweeter, more tender, of finer grain, moister, and with less tendency to dry out. In icings and fillings these shortenings produce a finished product which is smoother and more stable.

As in the case of all purpose shortenings the plasticity and plastic range

TABLE 49

COMPARATIVE ANALYSES AND PERFORMANCE OF HIGH ABSORPTION SHORTENINGS

	FFA, Per cent	Color R	Iodine Value	Congeal, °F.	Stability AOM, Hrs.	Monoglyceride, Per cent	ASTM Penetration		Solids Fraction Index				[1] White Layer Cake Volume, CC./100 Gm.	[1] Icing Volume, CC./100 Gm.
							70 °F. mm. × 10	92 °F. mm. × 10	50 °F.	70 °F.	92 °F.	104 °F.		
Hydrogenated vegetable														
Brand														
A	.03	1.3	72.3	95.2	140	2.86	143	250	32.4	20.6	12.4	7.1	284	142
B	.10	2.3	79.4	95.4	71	2.00	168	202	24.6	17.7	13.2	7.9	263	130
C	.11	1.2	72.2	95.6	114	3.43	154	220	26.6	20.3	14.2	7.9	294	125
D	.08	1.1	69.6	96.3	132	3.48	156	220	28.4	20.6	14.4	8.3	289	111
E	.08	1.0	72.8	92.9	215	2.82	163	242	29.1	18.5	11.9	6.9	278	125
Average	.08	1.4	75.2	95.0	134	2.92	157	227	28.2	19.5	13.2	7.6	282	127
Meat fat														
Brand														
A	.04	1.2	61.3	97.5	105	2.75	157	227	29.1	20.5	14.9	8.8	302	150
B	.11	1.1	60.4	101.9	79	2.20	178	211	29.0	22.4	17.4	11.3	274	116
C	.11	1.2	62.5	101.1	93	3.20	160	220	28.6	22.9	17.8	11.7	285	132
D	.11	0.9	70.8	98.3	137	2.83	140	177	27.7	21.4	15.9	9.7	323	140
E	.10	1.1	61.5	105.5	69	2.78	167	207	28.5	22.1	18.0	13.4	278	136
Average	.09	1.1	63.3	100.8	97	2.75	160	208	28.6	21.9	16.8	11.0	292	135

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[1] Armour and Company Control Tests Minimum Specifications........ 280 120

are of prime importance, and physical characteristics are similar to those of all-purpose shortenings.

The type and quantity of emulsifier must be carefully chosen and controlled for optimum results. The optimum ranges of emulsification are different for cakes and for icings. Since dual use of the shortening is desirable for most bakers the emulsifier is controlled in the area where these ranges overlap.

For certain applications such as whipped toppings or fluffy type fillings specialized shortenings are offered. These have emulsifier systems adjusted to obtain optimum results for the particular use. Polyoxyethylene sorbitan monostearates have been used by some manufacturers in these shortenings. Table 49 gives the analysis of a number of representative brands of high absorption shortenings.

High Stability Shortenings

These shortenings are widely used for deep fat frying and biscuit and cracker use where maximum stability is required. Both meat fat and vegetable oil products are produced and the shortening is invariably hydrogenated. Emphasis is on stability and stabilities by the AOM method generally exceed 100 hours. Plasticity and plastic range are less critical for this shortening and are compromised in part to obtain the high stabilities.

Hydrogenation is carried to the lowest possible iodine value consistent with minimum plasticity requirements and no stearin is added. As a result relatively less of the higher and lower melting point triglycerides are present and the product has a shorter plastic range than the all-purpose product.

In certain frying operations the sharper melting point is a very desirable factor since the shortening "sets up" on the surface more quickly and gives a drier or less greasy appearance. In certain doughnut operations this characteristic is essential to the proper glazing or sugaring of the doughnut.

Although basically more saturated, high stability shortenings actually have low melting points because of the absence of stearin. This lower melting point tends to give better eating qualities in certain high fat foods.

Typical analytical characteristics of high stability shortenings made from hydrogenated vegetable oils, hydrogenated meat fats and vegetable oils, and hydrogenated lard are given in Table 50.

Shortenings for Bread and Yeast Raised Goods

A number of manufacturers make specialized shortenings for these purposes containing high levels of mono- and diglycerides. These may be made from either meat fats or vegetable oils, although the former

TABLE 50

TYPICAL ANALYSES OF HIGH STABILITY SHORTENINGS

	Hydrogenated Meat Fats and Vegetable Fats	Hydrogenated Lard	Hydrogenated Vegetable Oils
FFA. Per cent Max.	.05	.05	.05
Color Max. (Lovibond 5¹/₄ in. Col.)	15Y 1.5R	15Y 1.5R	20Y 2.0R
Iodine Value	52	55	68
Wiley M.P. °F.	113	115	102
Congeal °F.	95	97	84
S.F.I. @ 50°F.	39	38	44
70°F.	27	30	31
92°F.	16	15	14
104°F.	8	10	3
Stability AOM Hrs.	100+	100+	100+

appear to predominate. Monoglyceride content approximates eight per cent which is the maximum permitted in standard bread. Preferred monoglycerides are those made from low iodine value fats.

As compared with straight triglyceride shortenings these shortenings exhibit certain advantages in the handling of doughs during fermentation and makeup. They also increase the tenderness and softness of the baked product and retention of softness over a normal shelf life period.

Bakers' Margarines

Margarines are essentially emulsions containing approximately 80 per cent of fat plus water, milk solids, salt, emulsifiers and certain other ingredients. Basically they are intended to simulate butter and are primarily used as table spreads. Flavor is developed in margarine by ripening the milk used in it with bacterial cultures and by the addition of diacetyl. The consistency of margarine is largely determined by the characteristics of the fat used in its manufacture. While for table spread use, high melting point and waxy consistency must be avoided, baker's margarines are not so restricted since they are used as an ingredient and not eaten as such. Therefore bakers' margarines have higher melting points and longer plastic range, being not unlike shortenings intended for the same purposes.

Puff paste margarine is a particularly tough and waxy product possessing the extensibility desired for roll-in operations. The base fat is very high melting and has wide plastic range, usually consisting of a blend of liquid oil with a high percentage of a hard fat, as for example 65 per cent cottonseed oil and 35 per cent oleostearin. The method of crystallization is important to the development of the desired consistency and several manufacturers still prefer the traditional method of water crystallization rather than the continuous crystallizing system used on other margarines. Puff paste shortening is similar to puff paste margarine except that it contains water instead of milk.

ANALYTICAL TESTS

Free Fatty Acid

The free fatty acid determination essentially measures uncombined fatty acid. In evaulating a shortening by this test different criteria are used for deodorized shortenings and for the natural flavored shortenings. Lard and oleo oil processed by normal means will have an appreciable free fatty acid content with a level of .50 per cent for lard and .35 per cent for oleo oil being considered generally acceptable; deodorized shortenings will usually have less than .05 per cent, although shortenings containing an emulsifier will frequently exceed this level. Within reasonable limits there is no correlation with performance; however, levels above those cited may be indicative of poor processing techniques.

Free fatty acid is a significant control test for deep fat frying operations, since it measures the degree of hydrolysis taking place during frying. In a well controlled continuous frying operation the free fatty acid will generally reach an equilibrium value and stay rather consistently at that value, since the rate of hydrolysis is balanced by the rate of vaporization of fatty acids and the dilution of the fat with fresh fat.

Color

The color of a shortening is of little importance functionally. Its value is esthetic in that a white product seems to be more acceptable. Within reasonable limits the color of the shortening is not reflected in the baked product. Colors on the melted shortening are determined on the Lovibond scale by visual comparison of a $5\frac{1}{4}$ inch column of oil with calibrated red and yellow glass slides. Customarily shortenings are bleached so that the color on the Lovibond scale is in the range of 10 to 20 yellow and 1 to 2 red. An extreme off color may indicate improper processing, or in some instances a poor quality raw material.

Iodine Value

Iodine value indicates the degree of saturation of a fat, and in specific cases, will indicate hardness or softness. In finished shortenings it is relatively meaningless by itself. As an example, meat fat shortenings will generally have iodine values 10 to 15 points lower than hydrogenated vegetable oil shortenings of equivalent physical and functional characteristics.

Stability Tests

The active oxygen method (AOM) is the most widely used accelerated test for the oxidative stability of a shortening. This consists of bubbling air through a sample of the fat at 208°F. and determining the time in hours for a specific peroxide value to develop. A peroxide value of 100 me. per kg. has been established as the standard end point by the A.O.C.S. However, other end points are sometimes specified for certain fats since they give better correlation with the actual organoleptic rancidity.

A modification of this test using a temperature of 230°F. is widely used. In this modification the end point is reached in about 40 per cent of the time required for the Standard method which is a very obvious advantage for control work.

The Schaal or oven test consists of holding a sample of the fat at a temperature of 145°F. until it develops organoleptic rancidity. This test is also adaptable to determining the stability of the fat in baked goods. A number of tests have been described based upon oxygen absorption. These are based on the phenomenon that when held under an atmosphere of air or pure oxygen there will be a sudden absorption of oxygen at the end of an induction period.

Because of the extremely complex mechanism of oxidation, there is no direct or simple correlation between these various tests. In specific instances of products requiring long shelf life, it has been customary to make actual extended storage tests and correlate this with the particular accelerated test being used. Ordinarily the stability of the fat by the accelerated method is established at a level which includes a considerable factor of safety.

Peroxide Value

The peroxide value is a measure of the content of reactive oxygen expressed as milliequivalents of oxygen per kilogram of fat. It is determined by a reaction with potassium iodide and titration of the excess with potassium thiosulfate. As indicated previously it is used as a measure of the end point for the AOM stability test. It is also a measure of the degree of exposure of a fat to oxygen. Deodorization reduces the peroxide value of fat to zero and deodorized shortenings will normally have a peroxide value of less than 1.0. A level of up to 4.0 is considered normal for good quality lard.

Congealing Point and Melting Point

These measurements are commonly made on shortenings and oils and are important control tests in the manufacture of shortening. Melting point is somewhat confusing as applied to a fat. Fats do not have sharp melting points as do pure compounds. Actually they are mixtures of many components both liquid and solid at a given temperature. Fats soften and melt in a gradual manner over a considerable range of temperatures, therefore, the term melting point has little meaning unless the method is specified.

The methods in common use differ principally in the end point. These end points are visual and some considerable training of the analyst is required to get results which correlate with other observers. Wiley melting point is perhaps the most widely used. In this test, a tablet of the solidified fat is floated in a test tube between layers of water and alcohol. The end point is that temperature at which the tablet assumes a spherical form.

The capillary or closed tube melting point is the temperature at which a sample contained in a small glass tube becomes completely clear. The open tube melting point sometimes called the softening point is the temperature at which a sample solidified in an open tube immersed in water will soften sufficiently to rise under the buoyant effect of the water. In general the open tube melting point will be the lowest of the three; the Wiley melting point intermediate and the closed tube capillary melting point the highest. The spread between these melting points will be greatest with fats having a wide plastic range and less with those fats with a short plastic range.

Congealing point is determined by cooling a sample of fat with stirring until the fat becomes cloudy. The sample is then allowed to remain quiescent in an air bath held at 68 F. Under these conditions a rise in temperature occurs and the maximum temperature reached is considered the congealing point.

These tests are all widely used by shortening manufacturers as control tests to determine the physical properties of the shortening. As isolated tests on finished shortening these have relatively little meaning. However, either alone or in combination, these tests may be highly significant to the shortening manufacturer who can relate them to the raw materials and processing techniques which he is using.

Dilatometry

This technique is very widely used by the shortening industry in describing and controlling the physical properties of fats. It is based upon the difference in density between liquid and solid fats. By measuring the change in density or specific volume of a fat sample at various temperatures an approximation may be made of the percentage of the fat in the solid phase at these temperatures. These values are usually referred to as the solids fraction index. A standard method for this procedure has been adopted by the American Oil Chemists Society (Anon. 1958B); however, different laboratories use variations of this technique and obtain slightly different values on the same fats. In most cases a correlation may be worked out between any two methods. Determinations may be made at any temperature, although commonly they are made at 50°F., 70°F., 80°F., 92°F. and 100° or 104°F.

The solids fraction index can, in general, be related to the physical properties of the fat over this temperature range. Fats with a wide plastic range will produce a flatter curve with less difference in S.F.I. at the various temperatures. Short plastic range fats will have a steep curve, generally being high at the low temperatures and low at the high temperatures. Here again, the absolute values are not completely significant and in the interpretation of these results some consideration must be given to the raw material fats used in the shortening.

Smoke Point

This is the temperature at which the fat will just begin to smoke. Actually the smoke point is, in most cases, related directly to the free fatty acid content of the fat, and all well deodorized shortenings (except those with emulsifiers) will have about the same smoke point. Regardless of the initial smoke point, any fat used in deep fat frying will rapidly hydrolyze and develop sufficient free fatty acid to lower the smoke point substantially.

The analytical tests so far described are basically control tests and as such are primarily of interest to the shortening producer. Although the tests described are the commonest ones, there are a great many other analytical tests of a physical and chemical nature which are used by certain manufacturers in their control of shortening. For the most part these tests cannot be directly correlated with performance of the shortening in a bakery product. Similarity of two shortenings in one or several of these analytical respects does not insure that they will be comparable in performance. Conversely two shortenings with considerably different analyses may give similar performance. In some particular instances, a specific factor in performance may be correlated with one or more of these analytical tests, although this is the exception rather than the rule. However, some familiarity with these tests is helpful to the baker in understanding some of the characteristics of the fats and oils which he uses in order that the significance of them may be properly assessed.

Perhaps a far greater interest to the baker are the tests performed on the finished shortening, which directly relate to its performance in his operation.

PERFORMANCE TESTS

Plasticity

This property of shortening which is often referred to in various terms such as "workability," or "hardness," is of great importance to the baker since it relates to the way the shortening handles and combines with other ingredients. Numerous ways of measuring this property have been proposed. The ones most commonly used are some variation of the penetrometer. The oldest and perhaps still the most widely used method determining this property is simply to "feel" the shortening. This method of course is subjective and difficult to translate into terms which can be widely understood. A number of methods which have been used to measure the plasticity of shortening were reported on by Rich (1942). The A.S.T.M. grease penetrometer method has perhaps been the most widely used. This is also representative of the principle used in a number of the other tests.

In this test a cone of specified dimensions and weight is placed on the surface of a sample of the shortening and allowed to sink in for a period of 15 seconds. The depth in 0.1 millimeters which the cone penetrates is reported. A measure of the plastic range, which is the temperature range over which a sample remains plastic and workable, may be obtained by making penetrometer measurements at two or more different temperatures. The less the difference between these readings the greater the plastic range of the shortening. Since shortenings change in plasticity with mixing, the penetration has obvious limitations.

Loska and Jaska (1957) have described a method for testing the hardness of shortening while it is being "worked." This device consists of a modified A.S.T.M. grease worker mounted on a farinograph. The torque required to force a perforated piston through the sample of shortening is recorded. On repeated strokes there is a decline in the torque required with the torque finally levelling out at a constant value.

Flavor and Odor Testing

Panels consisting of several trained members are frequently used in testing flavor and odor of deodorized fats and oils. Results are assigned a numerical grade from 1 to 10, based on the degree of flavor in the sample. Surprisingly good agreement and reproducibility are obtained by a well organized panel. Evans (1955) describes panel methods of flavor testing in detail.

Cake Tests

Since one of the more important functions of the shortening is its role in creaming and in leavening cakes, many shortening manufactures test each lot of shortening for this factor. It is customary to select formulas in which the function of the shortening is critical. For all purpose shortenings a lean pound cake formula which contains no chemical leavening is commonly used. With high absorption shortenings a 140 per cent sugar white cake may be chosen. Conditions of the test are kept constant so that the only variable is the shortening under test. Mixing is carried out in a room controlled at a constant temperature and the degree and techniques of mixing are standardized. Ingredients are carefully weighed as is the final batter. Various means may be used to insure the uniformity of other ingredients from test to test.

Specific gravity measurements may be made on the batter during mixing. In the case of a pound cake these measurements relate very closely to the actual cake volume on the finished baked cake, since the leavening here is largely due to the aeration of the batter.

After baking the cakes are measured for volume and scored for other characteristics. Various methods of volume measurement of cakes have been used including seed displacement and linear measurement of the height of the cake at various points. The total volume of cake may be reported or the cake may be weighed and its specific volume in terms of ml. per 100 gm. or ml. per pound used.

Icing Volume

Shortenings intended for use in icings may be tested for icing volume. This consists of creaming the shortening with powdered sugar and water and other appropriate ingredients, under controlled conditions. At specified intervals during the mixing specific volume is determined by filling a container of known volume with the icing and weighing it. The shortening is considered satisfactory if the volume of the icing exceeds a certain minimum value and is satisfactory in other respects. In testing certain icing formulas, particularly those containing high percentages of moisture, the icing may be held and observed over a period of time for the separation of free water.

It might be here observed that it is desirable to test a shortening intended for dual use in cakes and icings for both properties since performance in a cake does not insure good performance in an icing or vice versa.

Water Absorption

This test does not exactly simulate any particular operation. It consists of placing a weighed quantity of shortening in a mixing bowl and slowly adding water to it at a constant rate. The end point is observed when free water is observed in the bowl that cannot be incorporated into the shortening. The results of this test are usually expressed in the amount of water incorporated expressed as a percentage of the shortening used. All purpose shortenings will normally show less than 200 per cent water incorporation while good quality emulsified shortenings will generally absorb in excess of 500 per cent and up to 800 per cent of water. This test does not correlate directly with either icing volumes or cake volumes, since it is possible to have products with a low water absorption which perform well in both of the other functions. However, there does appear to be some relationship to icing volumes and extra high water absorption values will usually result in high icing volumes.

Creaming Volume

The creaming quality of a fat may be tested by somewhat simplified procedures rather than a complete cake test. A dry creaming volume in which only sugar and fat are creamed together may be run. However, fats which cream equally well at this stage may behave differently after the addition of liquids, therefore, a wet creaming volume including water is somewhat more meaningful.

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CHAPTER 6

R. T. Bohn
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Sugars

SUGAR USAGE IN BREAD

The amount of sugar used in bread or rolls is entirely within the discretion of the baker and, as a practical matter, depends upon whether the bread is a hearth type, such as French, Italian, and Vienna, or white pan bread. In Italian and some other hard crust breads and rolls, no sugar is used. In French and Vienna bread and rolls, the sugar is maintained at a relatively low level. Development of adequate crust color and the raising of the dough, therefore, depend on sugars naturally present and the maltose formed by enzymes from the starch of the flour. Sweetness, softness and other qualities which sugar imparts to white pan bread are not considered of primary importance in hearth breads.

Thirty years ago, pan bread formulas in the United States included as little as two per cent of sugar, which was consumed during fermentation, so that crust color depended largely on maltose. As a consequence, the bread required extended baking, it was low in moisture, and almost all volatile constituents were lost. Since that time, a steady increase in average sugar levels has taken place, and it is now not uncommon for bakers to use eight per cent. The increase over the years may be summarized as follows:

SUGAR USAGE IN WHITE PAN BREAD[1]

Year	Per cent	Year	Per cent
1920	2.0	1943[2]	4.0
1925	3.0	1947	6.0
1930	4.0	1950	7.0
1935	5.0	1958	8.0
1939	6.0		

[1] When dextrose hydrate is used in place of sucrose, the percentages are generally increased to compensate for lower fermentable solids and sweetness value.

[2] War Food Order No. 1 limited sugar solids in bread during the period 1942–1946.

SUGARS IN A BREAD DOUGH

Types

The sugars which may be present in a bread dough are of several different kinds, not all of which are fermentable. They consist of:

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(1) **Sugars Naturally Present in the Flour.**—Included are glucose, fructose, sucrose, maltose, all of which are fermentable; and oligosaccharides which are not fermentable. The fermentable sugars total about one per cent of the flour and are of considerable importance in the production of certain types of bread. In the sponge these sugars are fermented by the yeast before the maltose formed by enzymatic action.

(2) **Maltose.**—Formed by the action of alpha amylase on the starch of the flour. The quantity of maltose depends on amylolytic activity of the flour, which is a result of the enzymes naturally present and those added, and the quantity of starch susceptible to the enzyme action. The maltose so formed is of extreme importance in the production of all yeast raised bakery products.

(3) **Added Sugars.**—These are sugar (sucrose), fructose (levulose), glucose (dextrose), and maltose. The latter is present in corn syrups and malt products. Invert syrups contain levulose.

(4) **Polysaccharides.**—Which are present in corn and malt syrups in varying amounts. They are not fermentable. Their functional value has not been clearly defined.

(5) **Lactose.**—Which is present in any milk products used in the dough.

Fermentable Sugars

The fermentable sugars are either directly fermentable or become fermentable by hydrolysis or inversion. Glucose and fructose (dextrose and levulose) are directly fermentable whereas sucrose must be inverted or hydrolyzed into these two sugars. This process takes place very rapidly in the presence of the invertase of the yeast.

The process is as follows:

$$\begin{array}{ccccccccc} C_{12}H_{22}O_{11} & + & H_2O & \rightarrow & C_6H_{12}O_6 & + & C_6H_{12}O_6 \\ \text{Sugar} & + & \text{Water} & \rightarrow & \text{Dextrose} & + & \text{Levulose} \\ \text{(100 lbs.)} & & \text{(5.26 lbs.)} & & \text{(52.63 lbs.)} & & \text{(52.63 lbs.)} \end{array}$$

During inversion, sugar is combined with water, and each sugar molecule splits to form equal parts of two simple sugars—dextrose and levulose. In the process, there is a gain of 5.26 pounds of fermentable solids for every 100 pounds of sugar. The inversion of sucrose into dextrose and levulose is complete within the time required to mix a dough. As a result, the sugars available for fermentation by the yeast and for other functional properties in doughs made with sugar are glucose and fructose, the same sugars that might be added in the form of commercial dextrose hydrate or commercial mixtures of corn syrup and liquid sugar. Similarly maltose becomes dextrose by the action of the enzyme, maltase, and is then fermentable. There is, however, some evidence that under certain conditions, maltose is directly fermentable.

Non-fermentable Sugars

The non-fermentable sugars in yeast raised doughs are the polysaccharides or sugars of higher molecular weight than sucrose and maltose. These are present in flour and corn syrups. Lactose in milk and whey is also not fermentable by bakers' yeast.

FERMENTATION

Yeast must have a source of fermentable carbohydrate to produce carbon dioxide for proper leavening of the dough and for the development of the characteristic fermentation flavors of bread. These carbohydrates come from a breaking down of the starch in the flour and from the added sugar. In hearth breads, the fermentable carbohydrate is principally maltose formed from starch.

The production of maltose occurs in the fermentation of all yeast doughs, both straight and sponge, but not enough is formed in the dough stage of the sponge dough process to support active fermentation during proofing and baking. Modern bread production requires doughs which are fast-moving both in make-up and proof. To make them, high percentages of yeast and sugar are necessary.

It is generally accepted that a minimum of two per cent of sugar is necessary to produce sufficient carbon dioxide to sustain adequate gas production in sponge doughs, and at least three per cent in straight doughs. Sugar in greater amounts serves other functions which are important to crust color, sweetness, volume, etc., as well as providing fermentation tolerance.

Mechanism of Fermentation

Fermentation in baking refers specifically to alcoholic fermentation—the conversion of sugars into carbon dioxide and alcohol by the action of yeast. It is accompanied by changes in the physical properties of the dough resulting from the by-products of fermentation, the action of enzymes present in the flour, and the use of other ingredients in the dough.

The equation of fermentation, known as the Gay-Lussac equation, is:

$C_6H_{12}O_6$	+	yeast	→	$2\ CO_2$	+	$2\ C_2H_5OH$
Dextrose or			→	Carbon		
Levulose				Dioxide		Alcohol
100 parts				48.9 parts		51.1 parts

During fermentation, carbon dioxide dissolves in the water phase of the dough until saturation is reached. It is then trapped in the gluten and leavens the dough. Various acids, volatile flavoring substances, and higher alcohols, are formed in the dough through oxidation, combination, and synthesis of the products of fermentation.

Rates of Fermentation of Sugars

In sponge doughs, the yeast first ferments the sugars naturally present in the flour and then, after a brief period of adjustment, the maltose formed from the starch.

Sucrose is almost immediately inverted into dextrose and levulose, and as soon as the dough is homogeneous, sugar is no longer present as such. This is true in doughs made with as much as 20 and more per cent sugar.

Dextrose is fermented at a more rapid rate than levulose when both sugars are present (Koch *et al.* 1954). The levulose accumulates in the dough in greater proportion of the total sugars than dextrose.

Dextrose and levulose are fermented at essentially the same rate when either is present singly in the dough (Griffith and Johnson 1954).

Maltose is not fermented so long as the hexoses—simple sugars—are present. Yeast will, however, ferment maltose readily after an induction period when it is the only sugar available.

Lactose is not fermented by bakers' yeast.

Rate of Gas Production

Dextrose is fermented faster than levulose, but doughs made with sucrose produce carbon dioxide and raise the dough at the same rate as those made with dextrose hydrate. This is contrary to the general belief of the practical baker who may have observed that doughs made with dextrose appear to ferment faster than those made with sucrose. The observation is accurate only if the two sugars are compared at the same level of usage and not at the same level of fermentable solids. The concentration of sugar solids has an effect on rate of fermentation and a correction must be made for the lower solids in dextrose hydrate. Since sugar contains only traces of water and the sugar solids in a sucrose dough are increased as a result of inversion, 15.6 per cent more dextrose hydrate must be used to produce the same concentration of sugar solids. When this is done, doughs made with sugar produce gas at the same rate as those made with dextrose hydrate. The higher the percentage of sugar in the formula, the more important it becomes to make this adjustment.

Sugar and Fermentation Tolerance

Fermentation tolerance is described by a joint committee of the American Association of Cereal Chemists and American Society of Bakery Engineers in this manner: "A dough that can be taken a considerable time before or after the fermentation peak and produce good quality merchandise is said to have good tolerance."

The adequate production of carbon dioxide during the entire fermentation period is one of the two most important factors in fermentation tolerance, the other being the gas retention properties of the gluten. Modern bread production requires the use of high percentages of yeast and an adequate supply of sugar essential to support vigorous fermentation.

Because of the high percentages of sugars used in white pan bread in the United States, there is little danger of bread of inferior quality being produced by either the straight or sponge dough process.

It follows, however, from a consideration of the chemical composition of the two sugars that sugar provides more fermentable carbohydrates than an equal weight of dextrose hydrate and hence better fermentation tolerance.

Sucrose—		
$C_{12}H_{22}O_{11}$ + yeast	yields	$4\ CO_2$
342 grams		176 grams
Dextrose—		
$C_6H_{12}O_6$ + yeast	yields	$2\ CO_2$
180 grams		88 grams
Dextrose Hydrate		
$C_6H_{12}O_6H_2O$ + yeast	yields	$2\ CO_2$
198 grams		88 grams

Thus, it requires 198 gm. of dextrose hydrate to produce 88 grams of carbon dioxide, whereas only 171 gm. of sucrose are required to yield the same amount of gas. It is evident from this that 15.6 per cent more dextrose hydrate will be required to produce the same amount of carbon dioxide than any given quantity of sucrose.

This has been demonstrated by gas evolution tests both on synthetic nutrient solutions and on doughs. These tests show that sucrose provides more fermentable carbohydrates, and hence more fermentation tolerance in respect to gas production than does dextrose hydrate. Unless the two sugars are used on this basis, the sugars in a dough made with dextrose hydrate will be exhausted before those in one made with sucrose.

Residual Sugars in Bread

Residual sugars in bread, those remaining in the bread after fermentation of the dough, reflect the percentage used in the formula, the kind of sweetener, and the manner in which the dough is processed.

In sponge dough bread made with sucrose, the residual sugars are levulose and dextrose plus a small percentage of maltose, the amount of which depends on the percentage of sponge and the amylase activity of the dough. About two per cent (flour basis) of the sugar added is consumed during the make-up and proofing period. If dextrose hydrate is used, the residual sugars are dextrose and maltose. Bread made from corn syrup doughs also contains dextrose and maltose but the percentage of maltose is much higher because of the high maltose content of the syrup.

Since yeast ferments dextrose and levulose before it does maltose, when all three sugars are present in a dough, bread made by the straight dough process is high in maltose which accumulates while the other sugars are being fermented. The loss of added sugars in straight doughs is higher than in sponge doughs because of the longer time they are in contact with the yeast. About three per cent (flour basis) is consumed.

The residual sugar in breads made without added sugar is maltose produced from the starch. The fermentable sugars present in the flour are used by the yeast before it ferments the maltose.

Bread made by the brew process is, like straight dough bread, high in maltose because all the maltose present in and formed by amylase action on the starch of the flour is available to the yeast only a short time, during which dextrose and levulose are also present and are being fermented by the yeast in preference to the maltose. Since sugar is consumed in the preparation of the brew, or broth, instead of the starch of the flour as in the conventional sponge dough process, it is necessary to increase the percentage of sugar in the formula if the same flavor standards associated with the use of sweeteners are to be maintained.

Yield of Bread

Sugar influences the yield of bread obtained from a given amount of dough because it makes possible an adjustment in baking time and temperature to produce loaves of high original moisture.

The interior temperature of the loaf at which gelatinization of the starch occurs is reached within 8 to 10 minutes in the average white pan bread. If, because of low sugar content, bread must be baked an unduly long period beyond the point of gelatinization in order to develop crust color, a greater loss of moisture occurs with a correspondingly lower yield.

In the usual white bread dough, the weight of solids is about 57 per cent of the total weight. The remainder is water. The degree to which the yield of bread and residual moisture vary with the amount of water evaporated during baking is illustrated below:

Dough, Weight, Pounds	Moisture[1] Lost in Baking, Pounds	Weight of Bread, Pounds	Moisture in Bread, Per cent
100	5	95	40.0
100	7	93	38.7
100	9	91	37.3
100	11	89	36.0

[1] Loss of carbon dioxide, alcohol and volatile flavoring constituents is not included.

Although the moisture content of bread cannot exceed the 38.0 per cent established by the official standard of identity for bread, it is an important factor in the scaling weight of the dough. The difference may amount to as much as half an ounce in a one-pound loaf—a point not to be ignored in controlling production costs.

The high sugar formulas used in production of white pan bread in the United States in conjunction with modern oven construction make possible rapid baking and retention of maximum moisture.

The yield of bread from doughs made with sugar is slightly greater than from doughs made with an equal weight of dextrose hydrate if the same absorption is used, because the latter contains about nine per cent water. On a solids basis, the yields are not materially different.

Effect on Dough Properties

Absorption.—Sugar, in the percentages normally used, has little effect on the absorption of the dough. Additional mixing, however, is required to develop the dough as the percentage of sugar is increased. This is particularly important in high-sugar (20 to 25 per cent) doughs. In these the absorption will be much less than the maximum possible unless the dough is given the additional mixing time required to develop it to the maximum (Bohn 1959). If the dough is not given the required mixing time because of limited mixing capacity, or for other reasons, the baked product will lack volume and have a dry crumb and inferior eating and keeping qualities.

Since dextrose hydrate contains approximately nine per cent water, the water added to a dextrose dough should be reduced to maintain the same consistency as when sucrose is used. However, in practice this is seldom done. The necessary adjustment should be made in evaluating the economic usefulness of the two sugars.

Dough Development Time.—Sugar increases the time required to bring about maximum development of a dough. This effect depends on the percentage of sugar and is of little significance in bread doughs where a slight increase in mixing time will compensate for an increase in the percentage of sugar. In sweet doughs made with 20 to 25 per cent sugar, however, the mixing time is greatly increased (Bohn 1959). Such doughs are best mixed in a high speed bread mixer for at least a fifty per cent longer time than a bread dough. The increase in mixing time required when sugar is increased has been attributed to competition between the sugar and the gluten proteins for water (Baxter and Hester 1958). It makes no difference whether sugar is in the granulated or liquid form. The dough mixing time is the same regardless of which one is used.

Effect on Finished Product

Crust Color.—The color of crust of bread may vary from the light straw of hearth breads in which no sugar has been added, to the attractive reddish brown of white pan bread. To the baker, a rich color indicates a well-fermented dough made from a good formula, well baked into a loaf of pleasing flavor, and of good toasting and keeping qualities.

Crust color reflects the type and amount of sugars used in the formula. Dextrose, levulose, or maltose may be present in the bread, as well as lactose from any added milk solids. The temperature at which these sugars caramelize and enter into the browning reaction with amino groups determines the intensity of crust color at any given level of usage. Levulose is the most sensitive to heat. It caramelizes at a much lower temperature than dextrose and thus develops coloring materials more quickly (Bohn 1954). Dextrose, in turn, caramelizes more readily than sugar, but in bread doughs sucrose is no longer present as such since it is inverted into dextrose and levulose. As a result, the crust color of bread made with sucrose is a more reddish brown than that made with dextrose hydrate bread when the two sugars are used either on the same weight or same solids basis. Bread made with low percentages of dextrose (two per cent) has a lighter crust than when made with sucrose or invert sugars, evidence of the lower concentration of residual sugar solids (Johnson 1952). As the percentage of sugar is increased, the crust becomes darker under any set of oven conditions. The fact that sugar develops a richer, redder crust in commercial white pan bread makes it possible to use less sugar than dextrose to produce the same degree of crust color.

The tendency in the baking industry the last several years has been to increase the sugar content of bread in order to develop quickly an attractive crust color in the oven. This makes it possible to bake the bread rapidly and retain maximum quantities of flavor and moisture. In addition it has been shown (Baker and Mize 1939) that bread prepared without the formation of the typical crust lacks many of the flavor constituents associated with bread flavor.

Bread Flavor.—Bread can be made without added sugars, e.g., Italian and French hearth bread and English white pan bread. In these breads the fermentable carbohydrates come from those present in the flour and those formed by action of amylases on the starch of the flour. Breads of this type have a light crust color and inferior keeping and toasting qualities compared to typical American white pan bread.

Flavor is built into bread by the type and quality of the ingredients, and fermentation and processing of the dough. Of all the ingredients except salt, sugar has the most pronounced effect on flavor (Wiseblatt 1957). This is one of the basic reasons the baker of white pan bread uses more sugar than that required for production of gas. Consumer preference tests conducted by the U.S. Dept. of Agriculture show a significant increase in preference for bread as the sugar content is increased from 2 per cent to 7 per cent, that is, as the concentration of residual sugars increases.

Sucrose is superior to other sweeteners in its contribution to the flavor of bread because of its greater sweetness attributable to the levulose formed in the dough by inversion. An expert taste-testing panel (Snell 1952) using organoleptic methods of proved value, has shown that the relative sweetness values of the residual sugars in bread are reflected in the sweetness values of the bread. The most pronounced difference in sweetness was detected when bread containing eight per cent sugar was compared with one containing eight per cent dextrose hydrate. At this level of usage a substantial amount of levulose remains in the bread, whereas there are only traces of levulose in the bread made with dextrose. The superior sweetness of bread made with sugar at this level is readily discernible. The same test panel found bread made with 7 per cent sugar sweeter than bread made with 7 and 8 per cent dextrose hydrate. It was not until the sugar was reduced to 5 per cent and compared to 8 per cent dextrose hydrate that the breads were judged of equal sweetness. The samples studied placed the various loaves in the following order of sweetness:

Sweetening Agent	Per cent Used	Sweetness Rating (Overall mean Value)
Sugar	8	2.1
Sugar	7	1.8
Sugar	6	1.5
Dextrose hydrate	8	1.2
Dextrose hydrate	7	1.2
Sugar	5	1.2

Pilot consumer tests (Caul 1953) have confirmed these observations and are further affirmation of the fact that sweetness levels in bread parallel the sweetness ratings of the residual sugars.

Because sugar retards the action of yeast, it is not practical to use enough dextrose hydrate to duplicate the sweetness contributed by the high percentage of sugar used by many bakers. To replace 8 per cent sugar would require at least 12 per cent dextrose hydrate and this would seriously retard fermentation.

The by-products of fermentation are affected by many factors. The method used—straight or sponge dough, percentage of sponge, temperature and time of sponge, etc.—all influence the flavor of bread. As sugars are not added to sponge doughs until the sponge fermentation is completed, they contribute little if any to the flavor of bread attributable to fermentation. The sugars used in bread must, therefore, be evaluated on their contribution to the flavor as an ingredient.

In straight doughs, sucrose (after inversion) and dextrose are fermented before the maltose which then accumulates in the dough with the result that bread made by that process is high in maltose compared to bread made by the sponge dough process. The same is true of bread made by the brew process (Lee and Geddes 1959) whether used in conjunction with conventional equipment or with the processes for making bread doughs continuously. To develop in bread made by these processes the flavor which sugar contributes to sponge dough bread, it is necessary to use higher percentages of sugar. Thus, if seven per cent sugar is used in sponge dough bread, nine per cent should be used if the same flavor level attributable to sugar is desired.

Sugar also contributes to the flavor of bread by making possible more rapid baking. The crust then seals in many of the interior volatile constituents of the fermented dough before they are lost by distillation (Baker 1957).

Softness—Keeping Qualities.—Sugar is not a softening agent but, by developing crust color quickly, it makes possible a reduction in baking time and the retention of more moisture in the bread—a factor of paramount importance in the attainment of maximum initial softness. Breads of high sugar content which are baked rapidly have a softer crumb and retain more moisture than those with less sugar. Sugar is thus an important factor in controlling the original softness of bread which is the characteristic most desired in commercial white bread.

Sugar contributes little to the anti-firming properties and hence to the staling properties of bread as measured by subjective and objective tests. Increasing the sugar from 4 to 12 per cent has little effect on the rate of firming of the crumb (Cathcart and Edelmann 1950). Nor is there any difference in the effect of sugar and dextrose hydrate in this respect. These two sugars are alike in their effect on crumb firmness when compared by both the straight and sponge dough processes (Barham and Johnson 1951).

Sugar does, however, contribute to the moisture retention of the crumb of bread depending on the percentage used because of the residual levulose which bread made with it contains. This levulose absorbs moisture from the air depending on the equivalent relative humidity to which it is exposed. Bread made with a low sugar content or dextrose hydrate obviously contains little levulose and hence tends to dry out rapidly. In high sugar doughs made with 20 to 25 per cent sugar, such as those used for production of sweet rolls and coffee cakes, the percentage of residual levulose is high and has an important part in preventing the drying out of the crumb (Bohn 1959).

CHARACTERISTICS OF COMMERCIALLY AVAILABLE SUGARS

Sucrose (Dry)

Sucrose is available in various grades and it is important to a bakery operation to select the grades suited for the purpose intended. Most first-run granulated sugars are sufficiently standardized in color and other chemical compositions that grain size in the property that should receive primary consideration.

Table 51 indicates the approximate screen sizes of various types of sugars. It should be pointed out that not all of these grain sizes are offered by sugar refiners in all sections of the United States but there should be sufficient types available at all locations to satisfy general bakery operations.

From the foregoing it can be seen that there is a wide range of particle-sized sugars from which to select. Brief descriptions of each of these and their uses will be helpful for the bakery engineer.

Confectioners AA or Medium Granulated Sugar

Confectioners AA is a coarse crystal sugar some crystals of which are $^{1}/_{16}$ inch in largest dimension. This sugar is primarily used for sanding cookies, pies and other bakery products in which a very coarse grain is desired. This sugar is also frequently colored for decorative purposes.

Sanding Sugar

Sanding sugar is the most frequently used grain-sized sugar for sprinkling or sanding purposes for cookies, pies, bread, etc. It is less than half the average crystal size of Confectioners AA. It has the property of re-

TABLE 51

TYPICAL SCREEN ANALYSIS OF GRANULATED SUCROSE

Sieve Analysis										
Tyler Screen, Per cent on	U. S. Screen, Per cent on	Confectioners AA or Medium Granulated	Sanding	Bottlers, Manufacturers or Fine Granulated	Standard Granulated or Extra-Fine Granulated	Bakers Special or Fruit Granulated	Standard Powdered or 6X	Extra-Fine Powdered or 10X	Fondant and Icing	Dehydrated, Fondant, Drivert or Dri-Fond
8 Mesh	8 Mesh	...	...	...	...	...	...	...	...	...
10 Mesh	10 Mesh	5.6	...	...	...	...	...	...	...	...
14 Mesh	16 Mesh	59.0	...	...	...	...	...	...	...	...
20 Mesh	20 Mesh	27.4	9.3	T	T	...	...	...	...	...
28 Mesh	30 Mesh	7.4	49.2	4.3	0.1	T	...	...	...	...
35 Mesh	40 Mesh	0.4	37.6	74.5	13.8	0.4	...	...	...	...
48 Mesh	50 Mesh		3.3	18.6	40.2	1.7	...	...	...	...
80 Mesh	80 Mesh		0.3	2.3	40.6	24.8	...	...	...	...
100 Mesh	100 Mesh					32.3	0.3	0.1	...	...
150 Mesh	140 Mesh					31.6	1.8	1.4	...	...
200 Mesh	200 Mesh						6.6	2.4	...	...
270 Mesh	270 Mesh						8.2	3.0	..	..
325 Mesh	325 Mesh						10.8	7.0	...	...
Through last sieve		0.2	0.3	0.3	5.0	9.2	72.3	86.1	99.0[1]	99.0[1]

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[1] The extremely fine grain size of fondant and icing sugar makes the regular screen analysis impractical. However, practically all particles will pass through a 325 mesh standard sieve having .0017 inch openings. The average particle size of fondant and icing sugar is about 20 microns, i.e., .0008 inch.

flecting light and giving the products on which it is used a sparkling appearance.

Sanding sugar is also one of the lightest colored sugars available and is frequently used in the manufacture of fondants when a very light-colored product is desired.

Sanding sugar is also frequently used for making colored sugar for decorative purposes.

Bottlers, Manufacturers, or Fine Granulated Sugar

This coarse granulated sugar is only slightly coarser than the standard granulated and is frequently desired by bakers who have a mechanical-handling system, particularly for those using a delivery or in-plant pneumatic-handling system, or those who use screw-type conveyors for long distance transporting. Under these conditions the attrition is less objectionable since fewer fine particles are developed.

Standard Granulated, Regular Granulated, or Extra-Fine Granulated Sugar

Standard—or regular granulated—is the most frequently used product in the baking industry. It is sufficiently fine to dissolve readily in water or in other liquifying agents used in the bakery. It is, by far, the most universally used sugar in all types of manufacture.

This grain size sugar is also preferred by those large-volume operators who make the sugar into syrup before use. The coarser particles tend to disperse in water more readily than a finer product.

Bakers Special, Extra-Fine Granulated, or BCE Sugar

This product, as the name implies, is a fine granulated sugar and is particularly useful in cake manufacture. Its fine grain gives it a very fast solution rate in mixes and in those instances in which the shortening and sugar are creamed for leavening action, it yields a uniform cell structure and maximum volume cake.

Standard Powdered or 6X Sugar

Standard powdered sugar is the product which has been on the market for a good many years and for a considerable length of time was the standard product used for sweet-dough icings and as the major ingredient in icings on many of the "price" goods.

Extra-Fine Powdered or 10 X Sugar

This extra fine product is a relatively recent advancement. It has greater fines than the standard powdered sugar but still retains some portion of the coarse particles. When an icing is made from extra-fine powdered, the extremely fine particles contribute a creaminess to the icing which is not obtainable in the former product. At the same time it can be used in all other bakery operations such as doughnut dusting, etc.

Icing Sugar

Icing sugar, as the name implies, is a product made particularly for high quality icing production. As is shown in the Table 51, it has an average particle size of approximately 20 microns which give the icings prepared from it a very creamy appearance and texture. It promotes higher gloss, rapid crusting, and in most instances gives considerably greater mileage in spreadability which compensates for the premium normally charged for this sugar over powdered sugar.

Dehydrated Fondant, Drivert, or Dri-Fond

This product has been available on the Pacific Coast for a number of years and recently became available on the Atlantic Seaboard. As the name implies, it is a cooked fondant which has been dehydrated and is generally packed in 50-lb. multi-wall bags to facilitate handling in the bakery icing departments. Its standardized grain size and invert content permit reliable reproduction of results in the preparation of a fondant-type icing.

Brown or Soft Sugars

Brown sugars are offered in a wide range of color from a light yellow to a dark brown. In most areas of the country they are available at least in the medium and dark brown. These sugars are used primarily for the flavor they impart to the baked goods. They normally contain a relatively small amount of invert (from 1 per cent for the lighter varieties to 5 per cent for the darker varieties). Their organic and inorganic nonsugars are responsible for the flavor; the flavor in the lighter grades being mild, and inceasing in intensity as the sugars become darker. They can be used to advantage in dark breads, many cookies and in devils food, spice and other dark cakes.

NOTES ON STORAGE AND HANDLING OF SUGAR

Prevention of Caking in White Sugars

After the proper sugar is selected for use in a bakery, it is essential that it be given proper care to prevent it from caking and causing manufacturing problems.

If white sugar is kept dry at all times it will not cake. Sugar absorbs and loses moisture very readily with changes in atmospheric humidity. If exposed to a period of high humidity the normally dry surfaces of individual grains become moist with a thin film of syrup. If later the atmospheric humidities change to a dry condition, the sugar will lose the moisture. During this period of moisture loss, if the sugar is not moved the grains will have a tendency to cement together causing the entire contents of a bag or a sugar bin to become caked. The degree of caking will be dependent upon the amount of moisture absorbed and subsequently lost.

The most ideal conditions for storage of granulated sugar would be at constant temperature and constant humidity. This cannot always be achieved. Relative humidities under 60 per cent at a rather constant level are ideal for granulated sugar.

Inasmuch as many bakers today are receiving sugar in bulk, it is well to relate some of the background or information which has been found to give satisfactory results by this method of handling.

Sugar of the proper moisture content regardless of its temperature, will store and handle perfectly in bulk sugar systems. It is important, however, that the sugar be properly conditioned before delivery to the baker. The moisture of the sugar should be such that the ambient air surrounding the crystals has sufficiently low relative humidity so that no condensation occurs when this air touches the side walls of the transportation equipment or the storage tank. The proper moisture equilibrium, therefore, will obviously vary with the temperature that is apt to be encountered in the transportation and storage of the sugar. In winter months it will be necessary to have a lower moisture content than in the summer months. As a general rule, it has been found that if sugar is conditioned to the point where ambient air has a relative humidity of 30 per cent, the sugar will store with no caking.

Prevention of Caking in Brown or Soft Sugars

Brown sugars are essentially a fine-grained, granulated sugar with a film of heavy density syrup on the crystal surfaces. It is important that soft sugars be stored at comparatively high humidities—65 to 70 per cent are the most ideal. At these humidities, the sugar does not lose moisture and will stay in a soft friable condition. If brown sugar is exposed to long periods of low humidity such as that encountered during winter months in heated warehouses or bakeries, the syrup film dries out and becomes excessively sticky cementing the grains of sugar. If this does occur, the sugar can be reconditioned by exposure to high humidities for a period of time. During this period the sugar will absorb moisture and return to its normal condition.

Liquid Sugars

Liquid sugars are becoming more and more available in all sections of the country and have a very definite place in the bakery. Liquid sugars can be roughly classified into sucrose type, invert type and refinery syrup or liquid brown sugars. Table 52 indicates the typical properties of liquid sugars.

Sucrose Type.—Sucrose, as the name implies, is essentially a solution of granulated sugar adjusted to a density that can be shipped and stored without danger of crystallization.

Invert Type.—Invert sugars vary in their composition running from a small percentage of invert (the remainder being sucrose) to almost complete inversion. The most common invert type syrup used in bread production contains between 50 and 60 per cent invert on a solids basis. The solids in this type of invert syrup varies between 76 and 77 per cent. Its density is such that it readily blends with other ingredients and yet permits the addition of ice water to maintain proper dough temperatures when leaving the mixer.

Refiners Syrups or Liquid Brown Sugars.—Refiners syrups or liquid brown sugars are used in the bakery much the same as brown sugars are—namely, for their flavor. These products are standardized and lend themselves to automation much more readily than do bagged sugars.

Corn Sugars and Syrups

Commercial corn syrups and sugars of interest to bakery engineers are of three types:

Corn Syrups—clear, colorless, noncrystallizable, viscous liquids consisting of mixtures of dextrose, maltose, and higher saccharides.

Corn Syrup Solids—the solid substance obtained by dehydrating liquid corn syrup.

Dextrose—a pure crystalline solid.

Dextrose is the major dry corn sweetener. However, an increasing production of corn syrup solids is broadening the practical range of corn syrup by making this sweetener available to users equipped to handle only dry ingredients, and for applications requiring dry sweeteners.

Corn Syrups.—Corn syrups may be classified into the following categories: (1) low conversion—28 to 38 D. E. (dextrose equivalent[1]); (2) regular conversion—38 to 48 D. E.; (3) intermediate conversion—48 to 58 D. E.; and (4) High Conversion—58 to 68 D. E.

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[1] Dextrose Equivalent is common method for expressing relative composition of corn syrup solids based on the determination of dextrose equivalent, defined as total reducing sugars expressed as per cent of total dry substance.

Table 52

TYPICAL PROPERTIES OF LIQUID SUGARS

Invert, Per cent	Solids, Per cent	Degree Baumé	Specific Gravity	Pounds Per Gal.	Solids Per Gal., Pounds	Typical Composition, Percentage Wet Basis				
						Moisture	Sucrose	Invert	Ash	O.N.S.
Liquid Sugars										
0	66.6 ± 0.2	35.8	1.3288	11.05	7.35	33.50	66.47	0.01	0.01	0.01
10	68.2 ± 0.2	36.7	1.3386	11.14	7.60	31.80	61.36	6.82	0.01	0.01
25	70.5 ± 0.2	37.7	1.3510	11.24	7.93	29.50	52.86	17.62	0.01	0.01
40	74.8 ± 0.2	39.7	1.3766	11.46	8.57	25.20	44.86	29.91	0.02	0.01
50	77.0 ± 0.2	40.7	1.3903	11.57	8.91	23.00	38.48	38.48	0.03	0.01
90	75.0 ± 0.2	39.5	1.3745	11.44	8.58	25.00	7.50	67.46	0.03	0.01
Refiners Syrup										
Light	77.5 ± 0.2	41.5	1.4011	11.66	9.04	22.50	23.82	48.59	2.92	2.17
Medium	77.5 ± 0.2	42.4	1.4136	11.76	9.12	22.50	37.87	30.11	5.45	4.07
Dark	75.0 ± 0.2	41.8	1.4048	11.69	8.77	25.00	46.37	16.36	7.02	5.25

Note.—The above typical data are for liquid sugars available on the Pacific Coast. Other areas may have slightly different specifications and analysis.

Table 53

PHYSICAL CONSTANTS FOR CORN SYRUP

	Com'l Baumé at 140/60° F.	Observed Baumé at 100/60° F.	Specific Gravity at 100/60° F.	Weight Per Gallon in Lbs. at 100°F. in Air	Weight Per Cubic Foot in Lbs. at 100°F. in Air	Per cent Moisture	Per cent Dry Substance by Weight	Lbs. Dry Substance Per Gallon at 100°F. in Air
32 D.E. Corn Syrup	43.0	42.84	1.4184	11.813	88.366	20.41	79.59	9.402
42 D.E. Corn Syrup	43.0	42.84	1.4184	11.813	88.366	19.73	80.27	9.482
52 D.E. Corn Syrup	43.0	42.84	1.4184	11.813	88.366	19.06	80.94	9.561
62 D.E. Corn Syrup (NOT Ion-Exchange Refined)	43.0	42.84	1.4184	11.813	88.366	18.38	81.62	9.642
62 D.E. Corn Syrup (Ion-Exchange Refined)	43.0	42.84	1.4184	11.813	88.366	18.19	81.81	9.664

The high conversion syrups are further classified as acid converted and acid-enzyme converted.

Corn Syrup Solids.—Dehydrated corn syrup is available in several D. E. classifications—15, 28, 42 and 62. These corn syrup solids are essentially dry products containing between 3 and $3^1/_2$ per cent moisture. These dry products permit bakers who do not have receiving or storing facilities for corn syrup to take advantage of their special properties.

Corn Sugar.—Dextrose is a pure crystalline solid. It is marketed in two forms: a hydrous product containing approximately nine per cent water of crystallization, and an anhydrous product with a very low moisture content.

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CHAPTER 7

Richard H. Forsythe

Eggs

Eggs and egg products have constituted, over the last 20 years, one of the most complex and expensive ingredients which the baking technologist has investigated in problems of formulation, quality, and price control. It is the purpose of this chapter to summarize and present an evaluation of some of the data that have been accumulated on the properties of eggs and egg products as they affect the job of the baking technologist. The use of shell eggs in the baking industry is very limited at the present time because of the high labor costs involved in removing the shells, but will be discussed briefly here since the qualities of the original shell eggs contribute to the qualities of the egg products that are commonly used.

Eggs of all kinds have long played an important role in the nutrition of the American population. Nearly one-tenth of the total protein requirement of the adult is met by the consumption of eggs in one form or another. In 1957 the American public consumed approximately 360 eggs per capita for a total of over 61 billion eggs. About 90 per cent of the total eggs produced are used in the form of shell eggs for table use. About 7.5 per cent are manufactured into liquid, frozen or dried eggs for use in the baking and confectionery industries, with the remaining 2.5 per cent being used for hatching purposes. The usage of egg products in the United States in 1958 is shown in Table 54. For comparison purposes all figures have been converted to a dry basis as indicated in the Table footnote. The conversion figures are basically the reconstitution data commonly employed in the industry. It should be pointed out that almost 80 per cent of all the eggs used are used as frozen or liquid eggs, but there has been an increasing trend over the past ten years for the egg solids products to have a greater proportion of the total. It is anticipated that the baking technologist will rely more heavily on the egg solids products because of a wide variety of factors including convenience, less wastage, and lowered costs due to more economical handling procedures.

The egg products industry is centered in the middle western portion of the country with almost all of the frozen and dried eggs being produced in the West North Central States. This is primarily due to the fact that in these states farm flock production of eggs accounts for 27 per cent of

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the total national production, whereas only 9.2 per cent of the population reside in this area. The Western, Southeastern and Northeastern States, formerly deficit areas as far as egg production is concerned, have recently become nearly self-sufficient because of the large influx of commercial scale poultry and egg production in those areas. Since these developments have taken place more rapidly than the reduction in farm flocks in the Middle West, it appears likely that the Middle West will remain the source of egg products in the foreseeable future.

Table 54

USAGE OF EGG PRODUCTS IN THE UNITED STATES IN 1958

	Used as Dry		Used as Frozen or Liquid[1]		Total
Type	1,000 Lbs.	Per cent	1,000 Lbs.	Per cent	1,000 Lbs.
Whole	8,767	18.8	37,708	81.2	46,475
Albumen	8,834	35.7	15,950	64.3	24,784
Yolk	7,770	15.3	42,850	84.7	50,620
Total	25,371	20.8	96,508	79.2	121,879

[1] Converted to a dry basis for comparison purposes on basis of four pounds liquid whole egg equal one pound of whole egg solids, two and two-tenths pounds liquid equal one pound dry yolk solids, and seven and one-half pounds of egg white equal one pound of egg white solids.

PRODUCTION AND PROCESSING OF EGGS

Shell Eggs

Shell eggs for egg products as well as table eggs are generally produced by specially selected hybrid stock on farms ranging from 150 to 150,000 chickens. As indicated above, the middle western farm, the source of most egg products, is small with the average flock size in the vicinity of 250. While this information may appear to have little significance for the bakery technologist, it definitely affects some of the qualities of his egg ingredient. Shell eggs are produced on these farms and picked up once or twice each week by a local egg buyer who acts primarily as a collection agent. This "first" buyer accumulates and holds eggs under refrigeration and grades them into several categories. Eggs with the highest interior quality which show a very thick albumen and upstanding yolk are selected for the table egg market and are placed in cartons for shipment to consuming centers. Eggs that do not meet these rigid requirements are placed in 30-dozen cases and sold to egg breakers. It should be pointed out that the eggs delivered to the breakers do not have inferior qualities as far as those qualities required for breaking stock are concerned, since they generally include those eggs with small shell defects, thinner albumen, and lower yolk height. These organoleptic qualities obviously are of little importance when the egg is to be broken from the shell. One of the more important qualities is the strength of the egg shell as indicated by Stewart (1935). The shell strength determines whether or not the egg will be able to stand up in transit without breakage and to some extent the ability of bacteria to penetrate into the egg contents. Shell strength is controlled by breeding, by feeding such nutrients as calcium and similar minerals, as well as by the management of the flock. Whereas the color of the yolk is very important to the egg products user, most requiring as deep a yellow color as possible, it is of less importance to the table egg consumer although for the most part this market demands a lighter color yolk. From what has been pointed out above, it should be evident that the table egg market is more influential, because of volume, in having its demands met by producers. Yolk colors can be controlled accurately by including in the feed xanthophyll and similar carotenoid containing ingredients, for example, alfalfa meal. However, since there are a very large number of producers it becomes practically impossible to obtain dark colored yolks for breaking by controlling the practices on the farms. It must be assumed that the supply of naturally dark colored yolk will be decreasing in the future.

Most of the qualities of shell eggs can be estimated by a candling process. During candling, the egg is held before a bright light and the quality estimated by movement of the yolk and white, identification of shell defects or other imperfections in the egg or on the shell. Candling has long been recognized as an inefficient procedure for sorting into grades because of its subjective nature and several new items of equipment have been invented to improve the accuracy of this technique. Equipment is now available which will electronically detect small blood and meat spot imperfections in the egg, certain bacteria contaminated eggs, and, although it is not widely accepted, equipment has been developed for indirectly determining the thickness and the height of the white and the yolk.

The qualities of shell eggs that are of most importance to the egg breaker are the size of the egg, the yield of liquid edible egg products, strength of yolk membrane and bacteriological characteristics. A 30 dozen case of eggs can be expected to yield 20 to 22 pounds of liquid whites and 16 to 18 pounds of liquid yolk. The strength of the membrane surrounding the yolk is of considerable importance since in a weakened condition it permits the accidental inclusion of small quantities of yolk into the whites during the commercial breaking operation. The color of the yolk is another important quality attribute to the egg products user. All of these factors are influenced by the breeding of the chickens, the feeding of the chickens and the management of the laying flocks or the handling of the eggs in the collection channels delivering to the egg products manufacturer.

One of the most important economic factors to consider is the relative proportion of whites and yolks in the egg. Since the proportion is relatively constant, the demand situation for one must be proportional to the other or large price differentials result. This was typified by the extreme high prices for egg white that resulted from the increased demands when the angel food cake mix first came on the market. It is not generally realized that the relative proportion of whites and yolks differ when broken out commercially and in the laboratory. This has resulted in considerable confusion since most of the data that are available are those obtained in the laboratory. In the fresh egg broken in the laboratory, about 65 per cent of the total edible portion is egg white. When similar eggs are broken on a commercial scale, the egg white is approximately 55 per cent of the total, or almost 10 per cent less than would be expected from laboratory data. This is entirely due to the mechanical adhesion of the egg white to the yolk during the breaking operation. For example, in liquid egg yolk with 45 per cent solids, a standard item of commerce, approximately 14.5 per cent of egg white is included. Table 55 indicates the per cent solids, per cent fat and the amount of whites contained in various yolk products. These figures are based on laboratory data indicating that yolk contains 50.5 per cent solids, 31.9 per cent fat. Egg white contains 12.3 per cent solids and no fat.

TABLE 55

AMOUNT OF WHITES INCLUDED WITH COMMERCIAL EGG YOLK LIQUID AT VARIOUS SOLIDS LEVELS

Yolk Solids, Per cent	Yolk Fat, Per cent	Whites, Per cent
40	23.2	27.0
41	24.0	24.5
42	24.7	22.4
43	25.6	19.8
44	26.5	16.8
45	27.3	14.4
46	28.2	11.8
47	29.0	9.0

Egg Products

In the production of egg products, the shell eggs, after receiving at the breaking plant, are cooled to approximately 50° to 55°F., and candled as indicated above. Any eggs that have stained or dirty shells are removed at this point and thoroughly cleaned. The eggs are broken either mechanically or by girls who separate the yolk and the white and, after organoleptic examination, place them into containers which are collected at short time intervals. The egg white is filtered through metal screens and churned to produce a homogeneous mass. The egg yolk is handled in a similar manner, after which the product is thoroughly cooled and placed into 30-lb. cans for freezing or held for drying. Eggs are frozen in a blast freezer at −20° to −40° F. and after 72 hours are considered completely frozen. They are then held in refrigerated warehouses below zero, distributed in refrigerated trucks and held in frozen condition until used by the baker. After appropriate liquid treatments egg white is dried by either of two techniques.

Predrying Liquid Treatment.—The residual glucose in egg white must be removed prior to drying to retard the Maillard reaction. This is accomplished by one of three processes commercially. A controlled bacterial culture of a glucose utilizing organism of a type that does not constitute a health hazard is commonly employed. The acidity of the egg white is adjusted by appropriate food acids to create an environment favorable to optimum glucose utilization by the organisms. A yeast fermentation using *Saccharomyces cerevisiae* (Hopkins 1947) or *Torula monosa* (Kline and Sonoda 1952) is also employed. pH adjustment is required for optimum growth in the use of these organisms. A recent development (Baldwin *et al.* 1953; Baker 1952) is the use of an enzyme glucose oxidase in which the glucose of the egg white is oxidized to gluconic acid. In this instance, it is necessary to supply a source of oxygen which is usually hydrogen peroxide. Temperature must be controlled in all of these procedures to accomplish glucose removal in the specified time. Reaction temperatures are held between 85° and 95° F. and while the time can also be influenced by the amount of culture or enzyme added, usually a 12 to 18-hour period is considered optimum. "Whipping aid" additives are used to insure proper functional performance in the dried product (see p. 204). Following these liquid treatments the egg white can be dried on either a pan system or a spray drying system.

Pan Drying Egg White.—Pan or tray dried egg white is most commonly used in the confectionery industry but has found some acceptance by bakery technologists. A thin layer of egg white liquid is warmed either by hot air flowing over it or warm water underneath the pans while the moisture of the egg is evaporated to form a crystalline appearing product of about 14 to 16 per cent moisture. These crystals are then sorted for size and packed into either fiber drums or boxes. Pan dried egg white is also milled to form a fine powder which is more readily soluble than the larger sizes.

Spray Dried Egg White.—The spray drying of egg white is usually carried out in a drier of the Rogers type as shown in Fig. 33. Drying is instantaneous and a very fine powder results with moistures from 4 to 8 per cent. This product is packed into fiber drums or boxes usually with polyethylene liners.

Because of the fact that there is less residual glucose in egg yolk and whole egg than in the egg white, its removal is not carried out as extensively. The stabilized egg yolk and whole egg which does have the glucose removed, is manufactured almost exclusively by the use of the glucose oxidase system mentioned above. Because yolks and whole eggs readily support microbial growth, a larger quantity of the enzyme is employed and the reaction is completed in approximately three hours. No pH adjustment is required for this process although specified for some U. S. Department of Agriculture purchase contracts. Following glucose removal the egg yolk or whole egg is cooled to under 40°F. and held for drying. Fig. 34 shows the type of equipment used for this process. Egg yolk and whole egg are pasteurized at 140° to 143°F. for 3 to 3.5 minutes to reduce the bacteriological population. These products are immediately homogenized and spray dried in the type equipment shown in Fig. 35 to a moisture usually under five per cent. Yolk and whole egg solids are packed in fiber drums or boxes and should be refrigerated except in the case of the glucose free products where refrigeration is not normally required except for longer holding periods (see p. 207).

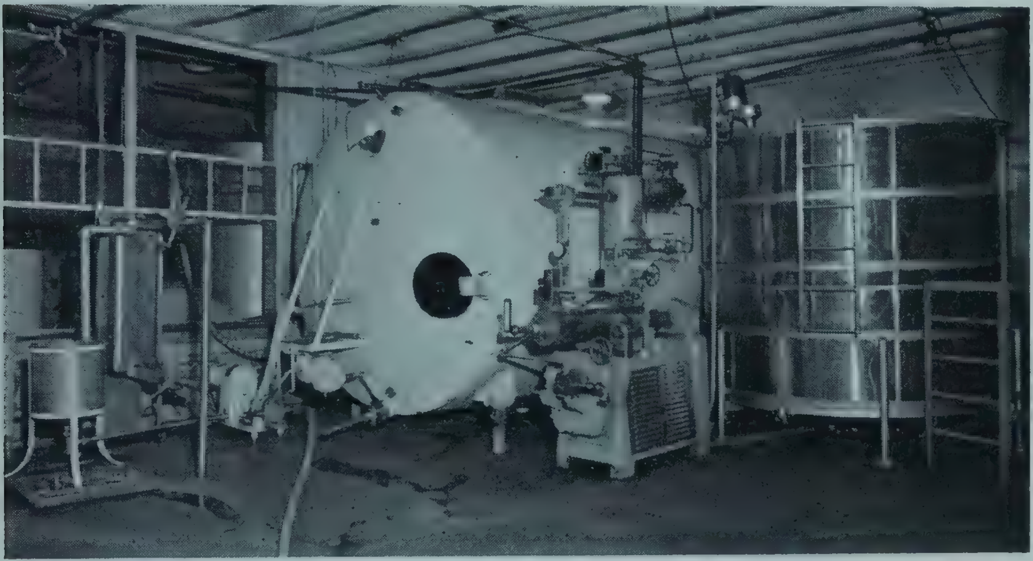

FIG. 33. STORAGE, PROCESSING, AND COOLING EQUIPMENT FOR LIQUID EGGS.

Plate sterilizer at left is part of equipment used to reduce bacteriological levels. Liquid egg must be kept cold at all times to insure top quality egg solids.

PHYSICO-CHEMICAL CHARACTERISTICS OF THE EGG COMPONENTS

Each of the major constituents of the egg has specific physico-chemical characteristics which affect their performance in the food industry. While some of these factors are not well understood, research is currently going on to elucidate their role as ingredients in bakery products and their interactions with other protein, carbohydrate and fatty materials.

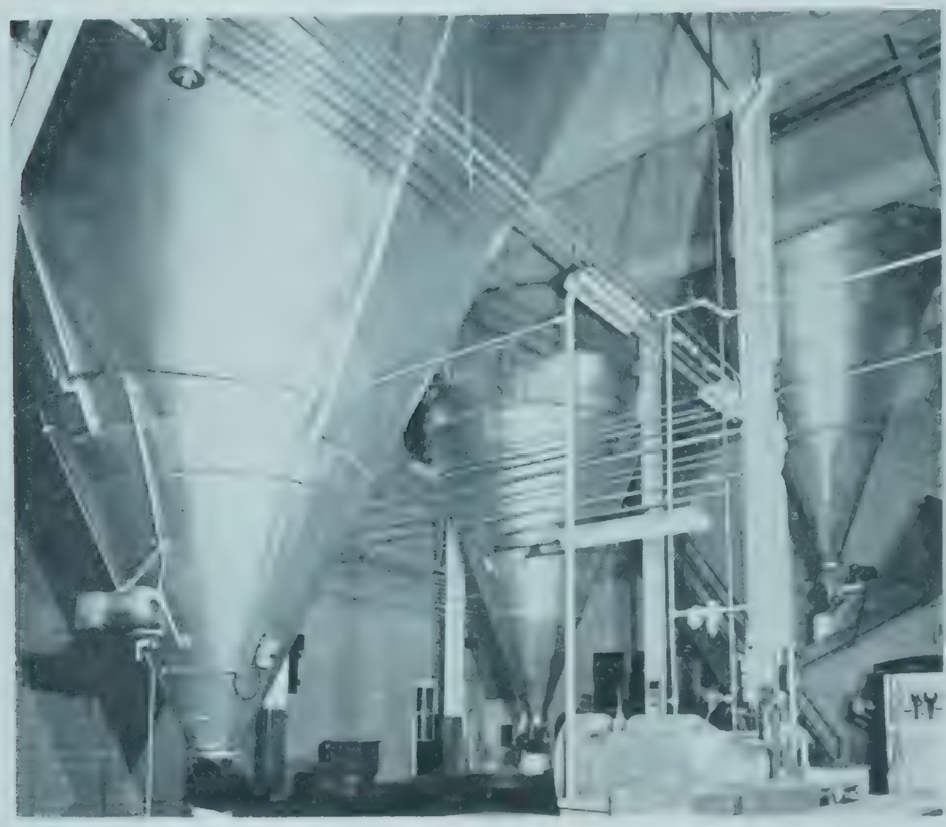

Fig. 34. Cyclonic Drying and Collecting Chambers Employed in the Manufacture of Egg Solids

All surfaces exposed to egg must be of stainless steel to insure highest quality and freedom from metal impurities.

Egg White

The egg white, although appearing to be a homogeneous liquid, actually is laid down in the egg as four separate layers (Romanoff 1943). As the egg ages the amount of the outer layer of thin white is increased with a concurrent reduction in inner layers of the thick albumen. This reaction, which is influenced by the loss of carbon dioxide and the temperature, is an important one in that it is the primary cause of the deterioration or the flattening of the egg white as normally seen on break ing out on a flat surface. These layers differ slightly in their total solids content from 11.2 per cent in the outer thin layer to 15.7 per cent to the innermost layer, with the average of the entire egg white being 12.1 to 12.3 per cent.

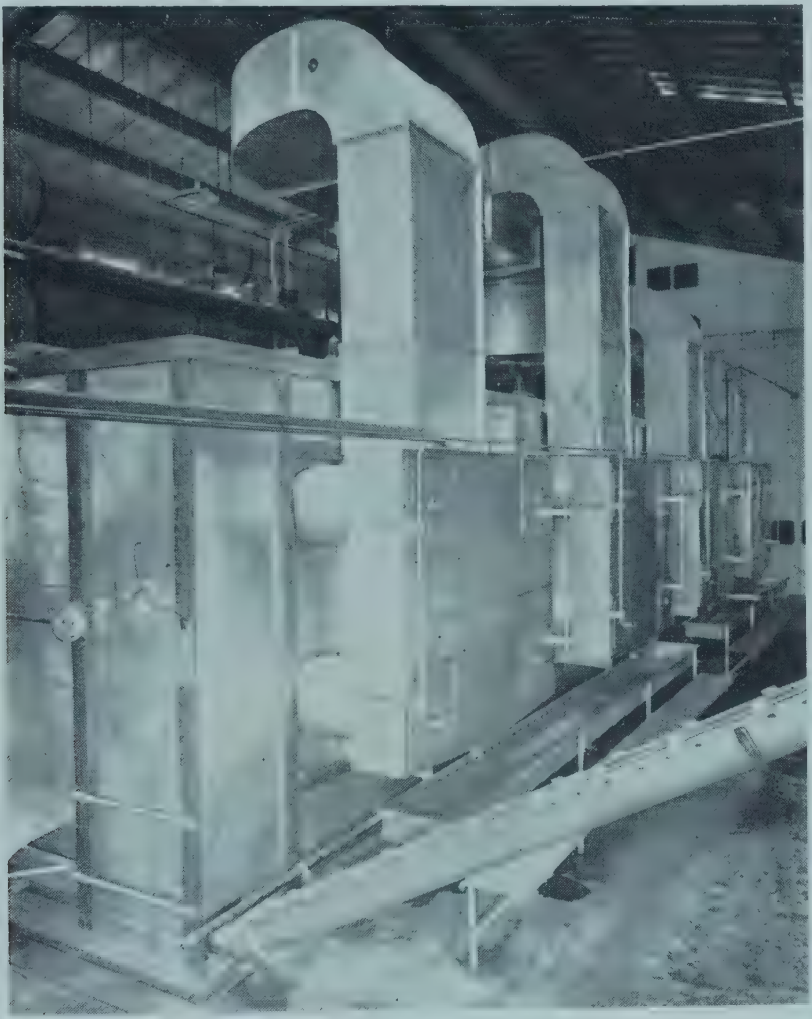

Fig. 35. Spray Drying of Egg White is Accomplished in a Rogers or Similar Type Drier

The innermost layer constitutes the "rope"-like structures that usually are found attached to the yolk. These chalazae serve the function of holding the yolk in place in the center of the egg. During the filtering operation in the processing of egg white most of this material is either removed or reduced in size.

The gross chemical composition of liquid egg white is as follows:

	Per cent
Water	87.7
Solids	12.3
Sodium chloride	0.3
Protein	10.7
Free glucose	0.38
Cholesterol	0.002

Approximately two per cent of the protein is of an insoluble keratin type called ovomucin. This protein, as will be shown later, plays an important role in bakery performance. A number of workers have reported on the protein composition with at least nine different proteins having been found. A compilation of three of these reports is shown in Table 56.

Table 56

INDIVIDUAL PROTEIN CONSTITUENTS OF EGG WHITE

	Found By		
	Longsworth (1940), Per cent	Forsythe & Foster (1950), Per cent	Csonka & Jones (1952), Per cent
Ovalbumin	58.9	63.6	58.4
Conalbumin	13.5	13.5	13.2
Ovomucoid	13.7	9.0	14.1
Total globulins	11.5	11.9	11.9
Lysozyme G_1	2.7	3.3	3.8
Globulin G_2	4.5	8.5	3.9
Globulin G_3	4.2		4.8

An excellent review by Everson and Souders (1957) gives the composition of liquid egg white and includes minerals, vitamins, lipids, and amino acids. Egg white is a particularly good source of riboflavin and biotin. Avidin, another protein found in minute amounts, is capable of binding protein, making it unavailable to some species in the uncooked white.

The pH of freshly laid egg white is approximately 7.6. During storage of the shell egg the pH increases due to the loss of carbon dioxide to approximately 9.5. During this change there is an accompanying change in viscosity, although as indicated above, the system is so inhomogeneous that viscosity measurements have very little meaning. During the processing of egg whites a more homogeneous mixture results and the viscosity is further reduced by reduction in the size of the insoluble ovomucin fibers (Forsythe and Bergquist 1951).

The proteins in egg white are very susceptible to denaturation by heat.

Denaturation as used here designates coagulation but other related changes occur and may be of significance to the baking technologist. Most of the egg white proteins when denatured become insoluble. In addition to denaturation by heat many chemical agents including urea, guanidine hydrochloride, salicylates and anionic detergents are effective denaturants and are also capable of redissolving denatured protein when used in a high enough concentration. Egg white denatures very rapidly at 130° to 135°F. and is almost instantaneously denatured at 140°F. Coagulation can be retarded by rapid agitation during the heating process. Viscosity has been widely used to measure the preliminary stages of denaturation before any evidence of precipitation or coagulation can be noted. Bernard *et al.* (1948) and Slosberg *et al.* (1948) showed that higher concentrations of sucrose elevated the denaturation temperature of egg white. Some inorganic salts (e.g., NaCl) as well as the protein concentration are also very effective. As the egg white protein is diluted with water, coagulation temperature is elevated. Coagulation or precipitation is not observed in the absence of salts. The denaturation is much more rapid and gelation takes place very quickly at pHs below 4.6 to 4.8 (for ovalbumin) the isoelectric point of the major protein constituents. Coagulation and precipitation are retarded or prevented at a high pH.

The use of egg white in the candy and baking industry is primarily based upon its ability to form foams stable enough to support large quantities of flour and/or sugar. These foams must be capable of holding these other ingredients until heat coagulation can occur in the oven and a stable protein matrix develops. To create foams a material with a low surface tension and low vapor pressure must be present. The substance on the surface of the foam must be capable of solidifying to form a solid matrix. A high viscosity is also helpful in the initial stages of the foam formation and the structure should be stabilized by the heat denaturation of the proteins. Egg white has characteristics which are essential for good foam formation. MacDonnell *et al.* (1955) have demonstrated that the globulins are primarily responsible for lowering the surface tension and increasing the viscosity to the point where rapid incorporation of air and the initial phases of the foam formation are possible. As the foam develops the bubbles become increasingly smaller, surfaces are greatly enlarged, and the ovomucin (and other proteins) undergo surface denaturation to form a solid film which contributes to the stability of the unheated foam. During this time the color changes from greenish white to opaque, the stiffness and the volume of the foam are increased. As further surface denaturation occurs the film elasticity decreases and finally becomes brittle or friable as the endpoint is exceeded. Surfaces change at this point from a shiny appearance to very dull.

Finally the ovalbumin which is readily heat coagulable, sets up in the oven to form a solid structure capable of supporting many times its weight of sugar and flour. The major efforts of egg technologists have been to study the factors affecting the formation of a foam. Not only the actual pH has been shown to be important but the type of acid used to adjust pH. Albumen between pH 6.5 and 9.5 has the greatest foaming power whereas at pH 5 a longer time was required. At lower pHs, however, the foam once formed is significantly more stable. Acid phosphates and potassium bitartrate have been found to be more effective in stabilizing foams than either acetic or citric acid. Very dilute aqueous solutions of egg albumen, curiously, foam greatest at their isoelectric point. Thuman *et al.* (1949) found that a 0.05 per cent solution of ovalbumin with an isoelectric point of 4.6 to 4.8 had the greatest foaming power at pH 3.7 to 4.0. They observed no foaming in the range pH 6 to 11 where a ten per cent solution of egg white has optimum foaming. Egg white at approximately 50° F. foams much less rapidly than at 86° F. but the stability of the foam is impaired. Temperatures above 115° F. tend to decrease both volume and stability of the foam. Recent studies have shown, however, that this observation may be dependent upon pH and that in some cases actual improvement can be detected at the pH of natural egg white. Research is currently being carried out to investigate further these findings.

Egg Yolk

The physical structure of the yolk of the egg is less defined than that of the albumen portion and is generally considered to be of little significance to either the consumer of whole eggs or egg products. However, it should be mentioned that the intact egg yolk consists of a number of strata, each containing a thin band of yellow and white yolk which can readily be observed when making a cross section of a hard cooked egg. Microscopic examination of the yellow yolk layers indicates an emulsion with quite varying globule sizes ranging from 0.025 to 0.150 mm. in diameter. The white yolk portion contains considerably smaller globules in the range of 0.004 to 0.075 mm. in diameter. These globular spheres indicate the degree of emulsification in the various layers. The vitelline membrane serves to contain the yolk in the intact egg, but is permeable to inorganic constituents and recent work by Smith (1959) indicates that this membrane may also be permeable to lower molecular weight lipid materials. As the egg ages this membrane weakens and during the breaking operation greater possibilities for contaminating the egg white with the yolk occur. The chemical composition of the yolk is considerably more complex than that of the white. On laboratory broken out eggs the following figures have been obtained:

	Per cent
Water	49.5
Solids	50.5
Sodium chloride	0.3
Protein	16.3
Fat	31.9
Glucose	0.17

The lipids of the egg yolk are composed essentially as follows:

		Per cent
Lipids of total yolk solids		63.9[1]
Glycerides		40.3
Total phospholipids		21.3
	Per cent	
Lecithin	13.1	
Cephalin	5.4	
Others	2.8	
Cholesterol		3.6

[1] Usually considered to be a minimum of 57 per cent in commercial egg solids.

Approximately 30 per cent of the total fatty acids are saturated and about 70 per cent unsaturated. Isolated egg oil is very sensitive to oxidation and softens and melts at about 80° to 90°F. The egg yolk is a rich source of many vitamins, being an excellent source of vitamins A, D, E, folic acid, biotin and choline. The pH of freshly laid egg yolk is approximately 6.0. As in the case of the white, the pH of the yolk increases as the eggs are stored due to a passage of bicarbonate ion or carbon dioxide gas through the vitelline membrane and out of the egg. The viscosity of liquid egg yolk is rather constant but can be changed by rapid stirring such as in a Waring type blender. As the yolk ages water moves across the vitelline membrane, reducing the viscosity of the yolk as follows:

Water Content of Yolk, Per cent	Relative Viscosity of Yolk, Water = 1
47.2	100
50.0	32.7
54.0	10.5
57.6	3.5

This viscosity of the yolk also is somewhat dependent upon the amounts of carbon dioxide loss and storage of eggs in carbon dioxide retards changes in the viscosity of the yolk. The density of the egg yolk depends upon the amount of water that has diffused into it across the vitelline membrane, but in the fresh egg is almost identical to that of the albumen with an average specific gravity of 1.035.

The egg yolk proteins are protected from the effects of heat by the relatively high amount of lipid material present. Egg yolk begins to coagulate at temperatures of 144° to 146° F. with a very pronounced rise in viscosity above 144.5° F. Coagulation is practically instantaneous at 158° F. Sugars have a protective influence on the coagulation of egg yolk proteins as noted above for egg white. As in the case of egg white, egg yolk coagulates at a higher temperature when diluted. Egg yolk exhibits a high degree of surface activity, the surface tension of the yolk being approximately two-thirds that of the albumen. Surface tension of albumen has been measured at about 50 dynes per centimeter at pH 7.8. As denaturation takes place, marked decreases in surface tension are noted.

While yolk is not commonly employed as a foaming agent with the exception of a yellow sponge type baked product, it does have characteristic foaming ability. The type of foam, however, is quite different from that produced when egg white is beaten, in this case being primarily an oil-water-air emulsion. The matrix of the emulsion is composed of surface denatured protein material from the yolk. The emulsifying ability of the egg yolk is used in many applications by the food technologist. Probably the most familiar is the manufacture of mayonnaise and salad dressings. As indicated above, egg yolk is already a well started emulsion at the time the egg product is manufactured. This is primarily due to the high concentration of phospholipids which not only are capable of maintaining the emulsion in a stable state but permit the inclusion of additional oil, water and other ingredients to build additional emulsified products and stabilize them. The lecithin is very likely complexed with the protein portion of the yolk in what has been called a lecithoprotein. Calcium ions are known to reverse the phases of egg yolk stabilized emulsions. Acids in the neutral pH range result in no inversion although coarser emulsions generally result.

Whole Egg

As would be expected, the properties of the mixed white and yolk are a combination of those properties that would be expected as far as chemical combination, nutritive value, and pH are concerned. The chemical composition of the mixed yolk and white is as follows:

	Percent
Water	74
Solids	26
Protein	12.7
Fat	11.6
Glucose	0.32

In thoroughly mixed whole egg, the structure of both the white and yolk is destroyed and can no longer be identified. Protein denaturation follows the pattern as discussed above for egg yolk rather than egg white, although critical coagulation temperatures are somewhat lower than the egg yolk. Whole egg performs as a foaming and emulsifying agent more nearly like egg yolk than the white because of the relatively high proportion of the solids being contributed by the yolk.

EFFECTS OF PROCESSING ON CHARACTERISTICS OF EGG COMPONENTS

The Breaking Process

The breaking process has certain marked effects on some of the qualities of the egg components of considerable interest to the baking technologist. One of the most important things is the contamination of the whites by egg yolk during the high speed breaking and separating of the eggs. Extreme care must be exercised both in the selection of the quality of the eggs to be broken and in the operation itself to maintain a contaminating level below 0.02 to 0.03 per cent. Above this level decreases in whipping ability of the egg white are observed. Small blood and meat spot imperfections must be removed during this process. Contrary to popular belief, these defects do not contribute to the microbial population of the egg as they are the result of small ruptures or detachments from the wall of the oviduct. During the churning operation a certain amount of cutting of the ovomucin fibers is desirable to create a more free flowing product. This is accomplished either in the churns themselves or by subjecting the egg white to the action of cutting devices similar to those encountered in a Waring Blender. This milling (MacDonnell *et al.* 1950), as it is commonly called, has the effect of reducing the viscosity and decreasing the whipping time required in the bakery. In the past bakers have been suspicious of this type of product because they suspected that the reduction in viscosity was due to the addition of water. With modern day inspection in breaking plants by Federal authorities as well as simple techniques to determine the added water, this should no longer be considered a problem.

The solids (and fat) content of the yolk can only be controlled at the breaking table. Breakers can control the amount of solids in the yolk by limiting the amount of whites which are retained with the yolk. Standards of identity for liquid egg yolk include a minimum solids figure of 43.0 per cent. For freezing purposes two products are produced, one with a minimum of 43 per cent solids and one of 45 per cent solids content. The amount of mechanical agitation or milling of the yolk has an effect on the viscosity not only of the liquid yolk but of yolk after freezing and defrosting.

Whole eggs are considered to be the product that results from the natural proportion of parts with no excess white or yolk being added. In many instances, however, whole eggs are standardized to a solids content of 26 per cent in the breaking operation.

An important quality attribute that can be controlled in the breaking process is the microbiological condition of the egg. Shell eggs, when broken, must move very rapidly through the entire process and be held at as low a temperature as possible to prevent microbial development. Egg products are cooled to under 40° F. either by plate type cooling equipment or packed into cans within 30 minutes of the breaking time. Plant sanitation at this point is extremely critical with frequent washdowns and sanitizing of the equipment required. All material with which the egg comes in contact is made of stainless steel to resist the corrosive action of the cleaning materials that are needed to remove egg soil.

The preparation of special mixtures of egg products is carried out in the breaking process. A common practice is to include ten per cent salt or ten per cent sucrose in some egg yolk to be frozen. The addition of salt or sugar prevents gelation of the egg yolk during the freezing process. Without these additives the phospholipids set up to a very firm gel which is difficult to make homogeneous in the bakery upon defrosting. If yolk could be frozen at temperatures above 25° F. it would retain its normal fluidity upon thawing. However, this is impossible due to the growth of microorganisms at these temperatures. The irreversible change which takes place apparently is the result of separation of water from the lecithovitellin complex which then precipitates. The effect of the sugar and salt may be to depress the freezing point of the water so that it does not separate from the lipoprotein complex. The choice of either of these ingredients depends upon the final use to which the product is to be put. Various other mixtures are produced which include whole egg, yolk and carbohydrate derivatives. The most common of these are usually called "tex" products with the egg portion consisting of from 60 to 70 per cent whole egg, 30 to 40 per cent egg yolk and from 8 to 10 per cent of the carbohydrate mixture. The most commonly employed carbohydrate is a corn syrup product having a dextrose equivalent from 24 to 60. The addition of corn syrup serves to prevent the gelation and is reported to improve the foaming and emulsifying ability of the liquid mixture.

Freezing

Freezing in itself has little effect other than mentioned above except to retain the egg products in the condition they were at the time of packing. Pearce and Reid (1946) carried out extensive studies on the storage of frozen whites and yolk for three months at —10°F. Their studies indicated that the freezing of whole egg lowered sponge cake volumes immediately after freezing but that increases occurred upon storage of the frozen egg to about the original level after three months. Many users of freshly frozen eggs refer to these products as "green." However, there seems to be insufficient data to support this conclusion in the literature. Work reported by Forsythe *et al.* (1953) on frozen fortified egg with corn syrup derivatives added, indicated that the freezing and thawing rates were much more important than the storage time or temperature. Viscosity of the finished product was altered significantly by freezing and thawing although performance in yellow sponge cakes was not significantly different between treatments. Pearce and Lavers (1949) had made the same observation with egg yolk and frozen whole egg, and concluded that the differences were not statistically significant. Probably the only factor that is of practical importance in the storage of frozen eggs is proper maintenance of temperature and the prevention of rust contaminating the eggs from the cans if the holding time is too long or the cans are allowed to sweat excessively during movement from warehouse to warehouse.

Drying

Since the effects of the drying techniques are quite different for white, yolk and whole egg products these will be considered separately.

Whites.—Of considerable importance in the liquid treatment of egg white is what are considered as pH and acid effects. Early Chinese albumen processors knew that albumen that was allowed to ferment, thereby increasing its acidity, whipped up better than one which had a higher pH. Some American workers formerly attributed this to the removal of glucose, but it is now definitely known that the effect of glucose, as indicated above, is a completely separate one and as such has no effect on the performance. The Chinese workers (Henningsen 1955) also knew that the length of time that egg white was held at a lower pH level had an effect on its whipping performance. The acid-binding properties of various proteins have been extensively reviewed (Waugh 1954). Fundamental studies have indicated a selective acid-binding power for different proteins and for different acids. From the practical production viewpoint this information can be utilized, and it manifests itself in the effect of acids on foam stability and on the temperature of heat coagulation.

These effects are completely different and separate from what is anticipated from the hydrogen-ion concentration. From the work of Neurath *et al.* (1944) and others (Cannon *et al.* 1941), it is known that the rate of denaturation from heat as well as from other forces is generally greater when the pH of a protein solution has been adjusted to its isoelectric point. Thus, we have a combined effect of the anion and cation of the acid added to the egg white during processing, whether it is added by the fermentation organisms or in the form of the food acids by the processor.

The effect of acid added to the "A" mix portion of an angel food cake mix is similar (Forsythe 1957). For example, phosphoric acid salts produce meringues which are more stable than those produced by tartaric acid salts (Lewis *et al.* 1953). The effect is noticeable even when the hydrogen-ion concentration is the same. Certain of the complex phosphoric acid salts result in more rapid foam formation as well as affecting their stabilizing influence.

The acid of choice for the pH adjustment of egg white during processing is either lactic or citric acid. Citric acid, of course, has the added advantage of sequestering any iron that might be present from contaminated equipment in the bakeshop, eliminating the possibility of the well-known iron-conalbumin reaction which gives a distinct pink color to meringue.

It has recently been discovered that certain other chemicals when added to egg white enhance the whipping performance. The English workers Clayton and Montgomerie (1937) showed that salts of bile acids were effective in retaining solubility and prevention of surface denaturation during spray drying. Mink (1939) patented the idea of adding anionic surface-active agents to egg white and presented results which showed significant improvements upon the addition of levels no greater than 0.1 per cent on a solids basis. Very little had been done commercially in this respect until the angel food cake mix manufacturers began to demand greater and greater foaming performance from products which had been primarily designed for the manufacture of candy. This demand set off a large-scale investigation of anionic surface agents as well as other chemical additives which might result in better performance.

In 1953 a patent was issued to Standard Brands (Kothe 1953) for the inclusion of triethyl citrate into egg white with results paralleling those of the addition of the anionic compounds.

In 1959, Kline and Singleton received a patent covering the use of bile salts for the improvement of the whipping performance of dried egg white

This patent would appear to be very similar to that ascribed to the British patent above.

Little or no scientific information is available to indicate the mode of action of these chemicals. Lundgren and O'Connel (1944) have studied the effect of alkyl-aryl sulfonates on egg albumen in an attempt to produce synthetic fibers. From their work it might be concluded that the effect of anionic surface-active agents is to increase the ease of surface denaturation permitting a more stable foam to be formed more rapidly.

An unintentional additive which has a decided effect on egg white, as indicated earlier, is fat. This factor, formerly not as well recognized as at present, undoubtedly accounts for part of the so-called "seasonal" effect on egg white quality. Eggs broken in the hot summer months usually show higher yolk levels unless special precautions are taken. The fat of egg yolk significantly retards the formation of foams and decreases their stability. The anionic surface-active agents, triethyl citrate, sodium desoxycholate and oleic acid salts overcome a portion of the damage resulting from yolk fat. These materials are effective, however, over only a limited range of yolk contamination. It is also apparent from observations in our laboratories that certain of the fats in flour contribute to instability of egg white meringues. This is a real problem in the preparation of an angel food type cake. Again very little is known concerning the theory of the mode of action of these fats, but a considerable amount of research is under way in various institutions to investigate this phenomenon.

A criticism of much of the egg white research that has been carried on in academic institutions is that much of it has been undertaken without a full knowledge of the effect of fat and these other chemical additives on commercial products. Results have been obtained which cannot be interpreted in the light of commercial practices.

It has commonly been accepted from the early days of albumen drying that it was possible to make a more satisfactory whipping product with pan-drying than with spray-drying techniques. Almost all of the Chinese albumen formerly used in this country and in many foreign countries was pan dried. As the need for better sanitation and larger quantities of egg white solids developed, efforts were made to replace the inefficient and costly pan drying procedure with spray drying. It was immediately noted that it was difficult and even impossible under some conditions to produce a satisfactorily performing product.

Bergquist and Stewart (1952), among others, investigated the reasons for this deficiency and concluded that the atomization during spray drying was responsible for the poor whipping product. Atomization creates tremendous surface areas which contribute to the loss of beating power, probably because of excessive surface denaturation. These workers also showed that not only the amount of surface formed but also the rate of surface formation was involved. The more rapid the formation of large surface areas, the longer the beating time. They suggested that if spray drying could be accomplished with less surface damage due to atomization, a satisfactory product would result. It has been the trend during the last five years to reduce atomization pressures as well as to develop new devices causing less atomization damage. It is now possible, with the combined use of acid effects, additive effects, and atomization effects, to produce an egg white product which is actually superior in performance to natural fresh egg white (although some formula modifications are usually necessary to take advantage of these improvements, see also p. 213.

The effect of heat treatments on dried egg albumen has long been considered, since the egg white is subjected to certain quantities of heat during the spray drying operation. Banwart and Ayres (1956) at Iowa State College carried out a comprehensive series of studies to determine the effect of heat treatment on the microbiological properties of egg white solids as well as on the functional properties. Their studies showed that it was possible to reduce significantly levels of Salmonella at moistures below six per cent at 122° F. without damaging functional performances. They actually observed an improvement in beating characteristics of albumen held under these conditions. Albumen held at higher levels of moisture suffered a loss of functional performance. It is apparent from their studies that no heat damage results during the actual spray drying operation. No theories have been advanced for the slight improvement noted during storage, but if we take our clue from the other investigations mentioned, this improvement may be due to the slight and possible selective denaturation of certain of the egg white proteins.

Yolks.—As indicated earlier, there is considerably less liquid treatment usually employed for egg yolk than for egg whites and consequently there are lesser effects on the qualities of the dried product due to processing factors. The primary change that takes place during the liquid handling is the development of micro-organisms if temperatures are not held below 40° F. The development of both spoilage type and health hazard type organisms occurs above this temperature. Predominant spoilage organisms are of the pseudomonas or similar types which attack the protein material with resulting off-odors and flavors. Primary pathogens encountered are of the Salmonella species although found generally in very low numbers. Extensive studies in our laboratories have shown that with proper processing conditions it is feasible to prepare egg yolk that contains less than three Salmonella organisms per 100 grams product

Pasteurization effectively reduces total microbial populations and is especially effective for the pathogenic types which with only a few exceptions are more heat labile than most other organisms. Some work has been done to investigate the effect of fat antioxidants on the keeping quality of yolk after drying. Little success has been achieved in this regard probably due to the very high state of emulsification which results in numerous surfaces of fat exposed to oxygen. According to Joslin and Proctor (1954), in the spray drying operation the emulsion of the egg yolk is modified to the extent that there is a considerable loss in foaming ability. This is particularly noticeable in the preparation of sponge cakes from egg yolk solids. There seems to be little effect on the actual emulsifying ability of the egg yolk as it has been shown that a satisfactory mayonnaise product can be prepared commercially with egg yolk solids. Kline *et al.* (1951) reported that the storage life of whole egg (and egg yolk) is determined primarily by three factors. The first two of these involves the reaction between glucose and proteins (the Maillard reaction) and the phospholipid cephalin moiety of either the proteins or lipoproteins. These can be retarded effectively as indicated earlier by the removal of the glucose. The third deteriorative reaction that takes place is the typical oxidation of fat which results in rancidity. This reaction is retarded by low temperature storage, inert atmosphere packing, and apparently also is affected by the original bacterial population of the liquid yolk. This may be due to the presence of fat splitting bacterial enzymes. The expected shelf life of stabilized egg yolk solids (glucose free) can be estimated as follows:

Storage Conditions	Shelf Life
35 °F.	9 months
75 °F.	6 months
85 °F.	4 months
95 °F.	2 months
110 °F.	2 weeks

These estimates are based primarily upon flavor changes as there are only minor changes in chemical composition or functional performance.

Whole Eggs and Other Products.—Processing variables have essentially the same effect on whole egg products as described above for yolk. The deterioration of the fat is somewhat less pronounced since the fat content of whole egg solids is 41 per cent compared with the yolk at 57 per cent. The most important effect that processing has is the effect of atomization and drying on the foaming ability of the whole egg. This is more critical in the case of whole egg products since they are widely used in the baking industry to produce foams.

Brooks and Hawthorne (1943) and Conrad *et al.* (1948) in extensive studies showed that the addition of carbohydrate materials prior to drying retarded the effects of storing at high temperatures and retained the functional performance required for making sponge type foams. These studies showed sucrose to be most effective with glucose and other lower molecular weight carbohydrates to be somewhat less effective. Dextrins in these studies retarded off flavor development but had little effect on the aerating power. Conrad concluded that this damage may result from the shearing action necessary when liquid egg is sprayed through nozzles under high pressure and that this energy may disrupt the emulsion and even surface denature the egg protein. They concluded that the heat is incidental and that it is probably the moisture removal that is of greater consequence. The moisture loss probably results in removing the protective atmosphere of water which normally surrounds lipoproteins and that carbohydrates with their abundance of hydroxyl groups replace this protective atmosphere.

BAKERY FUNCTIONS AND PRODUCT TYPES

A wide variety of egg solids products have been developed and are commercially available for specialized application in the baking field. Typical specifications for some selected products are shown in Table 57. In the development of these products primary attention has been paid to the functional and organoleptic roles demanded in the different products.

Standard Whole Egg Solids

This product is used in cookies, layer cakes, pound cakes and others where the functional role of the egg does not include primary leavening or foam formation, although when properly formulated such applications may be possible. Widespread use is found in institutional products. Three pounds of water and one pound of whole egg solids are used to obtain the liquid equivalent of fresh whole egg.

Stabilized Whole Egg Solids

This product is identical to the above mentioned except that the shelf life has been extended by the removal of the residual glucose naturally occurring in the egg. This process permits its use in grocery product mixes and makes cold storage unnecessary. (The usual commercial practice is for the egg manufacturer to hold this type of product under cold storage until delivered to the customer when no further refrigeration is necessary.) Many institutions use this product to eliminate "old inventory" problems.

TABLE 57

TYPICAL SPECIFICATION DATA FOR THREE SELECTED EGG SOLIDS PRODUCTS

	Whites, Spray	Yolks, Stabilized	Whole Egg Stabilized
Moisture	8 per cent Max.	5 per cent Max.	5 per cent Max.
Fat	Negligible	57.0 per cent Min.	40.0 per cent Min.
pH	6.5–7.5	6.5 ± 0.3	7.5 ± 0.4
Protein	80 per cent Min.	30 per cent Min.	49 per cent Min.
Color	Creamy characteristic	Specified on purchase	Specified on purchase
Odor	Bland	Bland	Bland
Reducing Sugar	0.1 per cent Max.	0.1 per cent Max.	0.1 per cent Max.
Total Bacteria Count	10,000/gm.[1]	50,000/gm. Max.	50,000/gm. Max.
Yeast	<10/gm.	<10/gm.	10/gm.
Mold	<10/gm.	<10/gm.	10/gm.
Coliform	<10/gm.	<10/gm.	10/gm.
Granulation	Through USBS #100 97 per cent Min.	Through USBS #16 100 per cent	Through USBS #16 100 per cent
Performance	Specified on purchase	Specified on purchase	Specified on purchase

[1] Only specified when low bacteria count products needed. Purchased usually at price premium.

Fortified Whole Egg Solids

A variety of products are manufactured under this category consisting of mixtures of whole egg and yolk in various proportions. The common proportion is about 70 per cent of liquid whole egg and 30 per cent liquid yolk, which when dried results in a product having slightly less than one-half egg yolk solids and slightly over one-half whole egg solids. Such a product finds application in formulations requiring both whole egg and yolk, or egg whites and yolk. Economic considerations often determine the extent to which this product is utilized. At the present time it has found widest use in the baking industry in layer type cakes, cookies, and sweet goods. Depending on the formulation, 2 to 3 lbs. of water and 1 lb. of this product give the approximate composition of the liquid mixture.

Whole Egg Solids—Special Blends

A number of specialized types of whole egg solids are manufactured which consist of either straight or fortified whole egg and some type of carbohydrate solid. Formerly the most standard of these products was one containing whole egg solids and sucrose (20 to 30 per cent solids basis). The primary purpose of the inclusion of the sucrose or other carbohydrates is to retain the leavening or foaming ability of the egg solids as previously described. These products go into solution more easily and retain a high degree of the emulsifying ability of the fresh egg. They find application in sponge and other foam type cakes and widespread use in the cookie industry. The reaction between sucrose and the lipid fractions of the egg results in the rapid development of off-flavor and odors at room temperature. Since 1950 carbohydrates other than sucrose derived from corn products have gained favor by greatly increasing the shelf life. Corn syrup derivatives with D. E. from 24 to 60 are commonly employed in the egg industry at a final concentration in the egg solids of from 20 to 30 per cent.

Standard Egg Yolk Solids

This product is used in layer cakes, doughnuts, sweet doughs, cookies and most other applications where liquid yolk would be used in baked goods. Egg yolk solids do not retain all of the leavening, foaming or emulsifying ability of fresh or frozen egg yolk and so are not recommended for use in sponge type mixes unless special formulations are employed. Egg yolk solids are used where a rich natural egg color and flavor are desired. The most widespread use of egg yolk solids at the present time is in institutional doughnut mixes, but they are finding increasing use in the bakery. One pound of egg yolk and one and one-quarter pounds of water are equivalent to liquid yolk. It is generally recommended that this product be held under refrigeration.

Stabilized Egg Yolk Solids

Additional shelf life can be obtained by the removal of glucose as in the case with whole eggs. The product can be used for the same applications as regular egg yolk. It is expected that the use of this product will increase compared to the standard product. Cold storage is needed for this product only in the hot summer months.

Egg White Solids

Egg white solids can be used in any application where frozen egg white has been employed. Greatest savings have resulted when used in angel food cakes because of reduction of scaling losses and waste. By actual test 0.6 per cent liquid egg white has been left in 30-pound cans discarded from bakeries. The spoilage of defrosted frozen whites is another major source of waste.

FORMULATION

According to recognized baking technologists (Pyler 1952) there are at least six functions performed by eggs in cakes and similar products. Generally these are listed as follows: (1) binding action; (2) leavening action; (3) emulsifying action; (4) flavor; (5) color; and (6) nutritive value. While the basic functions of egg solids are identical to those of frozen eggs, in many cases special properties have been "built in" egg solids and the maximum value of these products cannot be obtained without minor changes in formulation and mixing techniques. This is particularly true in the case of blends of egg and other ingredients designed to fulfill special functions and may seem to be an inconvenience to the busy baker to take time to reformulate. It has been demonstrated, however, in many instances that the time and trouble is amply rewarded by savings in ingredient and production handling costs. Most egg solids manufacturers can supply technical service personnel to assist in the formula readjustments.

Forsythe and Miyahara (1959) have reviewed the problems of formulation when new egg ingredients are employed. Since in many ways egg solids are new ingredients the following suggestions should be kept in mind: (1) the weight of the sugar should exceed the weight of the flour; (2) the weight of the total liquid should equal or slightly exceed the weight of the sugar; (3) in pound or layer cakes, the weight of the *egg solids* (whole egg or yolk enriched whole egg) should approximate one-quarter of the weight of the shortening; and (4) in white cake the weight of the *egg white solids* should exceed one-tenth of the weight of the shortening.

Sugar, shortening, leavening agents and liquid or frozen whole egg or yolk products are commonly accepted as tenderizing agents in cakes. Fat-containing egg solids contribute more tenderizing action than the similar type of liquid egg because of the state of the emulsion effected by homogenizing prior to and during the drying operation. Egg yolk solids tenderize more than whole egg, while egg whites actually act as a toughening agent, hence in the use of blends care must be taken to examine the relative proportion of yolk, whole egg and whites. Toughness is also contributed by flour and milk solids, and proper balance may mean a slight increase in one of these ingredients.

Sugar, liquids and eggs generally contribute to the moistness of the baked goods but due to the "protein bound" water, egg solids are slightly less effective than liquid eggs and proper formula balance may indicate reducing milk solids or flour or increasing sugar or water.

The leavening action of whole egg and yolk solids is reduced slightly in some cases and should be adjusted for by increasing leavening about one-quarter ounce per one pound of liquid egg replaced to maintain volume.

Probably the best way to illustrate the above formula balancing requirements would be to cite the example of replacing liquid whole egg in a retail yellow cake formula with a fortified whole egg (about 60 per cent whole egg solids + 40 per cent yolk solids) as shown in Table 58.

It should be pointed out that the amount of milk solids has been increased slightly to give additional "toughening" as previous tests had indicated some shrinkage on cooling. For the same reason, and also because of excessive tenderness in test bakes, the leavening was reduced. In this instance a slight loss in volume was experienced but the baker felt that the other characteristics were of greater importance and made an over-all "better cake" for him. Over-mixing may be a definite problem unless creaming and mixing techniques are modified as egg solids, being already homogenized and in a fine state of emulsification, can be mixed more rapidly. It will be obvious to the experienced baking technologist that this illustration will not fit every bakery and should only be used as a guide.

Table 58

COMPARISON OF FORMULA AND MIXING INSTRUCTIONS FOR LIQUID EGG AND EGG SOLIDS IN RETAIL YELLOW CAKE

Liquid Egg Mixing	Flour Weight Basis, Per cent	Ingredient	Flour Weight Basis, Per cent	Egg Solids Mixing
Place shortening in bowl and dry ingredients on top. Blend 2 min. at low speed. Add water, mix for 6 min. Scrape down to prevent lumps.	100	Flour	100	Blend all dry ingredients on low speed for 2 min. Add shortening, mix $^{1}/_{2}$ min. or until fat is size of "marbles." Immediately add 1st water, mix for 5 min. on 2nd speed (of 3-speed mixer).
	140	Granulated sugar	140	
	10	N. F. milk solids	12	
	6.25	Baking powder	5.25	
	3.75	Salt	3.75	
	55	Shortening	55	
	50	Water	80	
	60	Liquid whole eggs Fortified whole egg solids	15	
Stir eggs and water together, add in three equal portions. When all liquid is added, finish at low speed for 5 min.	45	Water	60	Add 2nd water in two parts, scraping down after each addition. Mix in 1st speed for total of 5 min. *Do not over-mix.*

In the case of egg white solids used in angel cakes, chiffon cakes, meringues and cheese cakes, where the egg white would normally be beaten and other ingredients folded in, again some formula balancing will be required to obtain maximum performance at minimum cost. Angel cakes made with egg white solids are invariably more tender than those made with frozen whites and the meringue can be whipped to a stiffer drier stage than frozen without over-beating. A primary difference between frozen and dried egg white solids is the pH; that of the frozen is usually 8.5 to 9.5, while the dry product is 6.5 to 7.5. The pH of the solids is adjusted to this level to better control over-all functional performance and this is easily adjusted for in the formula by reducing the baking acid by about 50 per cent. For optimum beating performance the pH of a meringue should be between 6.5 and 7.0, whereas for optimum cake volume the pH of the batter should be between 5.0 and 6.0 where heat denaturation is more rapid. The egg white solids should always be dry-mixed with a portion of the sugar to avoid "splash-out" during the early stages of beating. Many users have found it desirable to replace up to 50 per cent of the flour with suitable wheat or corn starch to give a batter much less susceptible to mishandling in the bakery, a larger volume cake, a finer texture and one which gives better eating quality in the finished product. This is true for both frozen whites and egg white solids, but is a particularly desirable combination for the solids.

In general, egg solids should not be reconstituted with water alone as this step is unnecessary with the very soluble products on the market today. The most satisfactory way to handle all egg solids is to blend or sift with the other dry ingredients. After formula balancing of the type illustrated above and appropriate modifications in mixing technique, egg solids have proved to give savings in cost of production mostly due to elimination of waste of ingredients and savings in shop labor.

TESTING EGG PRODUCTS

One of the greatest needs in the field of quality control and the promulgation of adequate purchase specifications for all egg products is better standardizing of laboratory test methods. As will be indicated below, some methods are available but are not applicable to the baking technologist's needs as the interpretation of the results does not give an accurate picture of the product's functional performance. This is the case due to the fact that eggs are used in such a wide variety of products that functional testing by the manufacturer has not been practical.

The Institute of American Poultry Industries maintains a laboratory for the benefit of its members and customers of the egg industry in which all routine tests can be carried out. Another function of the Institute is to supply standard test methods for the producers and users of egg products. A permanent committee of the Institute develops and evaluates new methods that are published in the scientific journals.

Sensory Tests

Many research papers have been published on the sensory evaluation of food products. It is outside the scope of this chapter to review these subjective evaluation procedures. Only one test for palatability is considered standard and is used throughout the industry for whole egg products. This test is as follows:

Reconstitute 30 grams of whole egg solids completely with 90 ml. distilled water in 400 ml. pyrex beaker. Place beaker in gently boiling water and stir at intervals while coagulation takes place. When coagulated to the consistency of scrambled eggs, the sample is ready for the palatability test. Good quality reconstituted egg powder, fresh shell eggs and storage shell eggs when available should be served periodically as a reference standard.

PALATABILITY SCORES

Score	Description of Quality
8	No detectable off flavor, comparable to high quality fresh shell egg
7$^1/_2$	Very slight off flavor
7	Slight but not unpleasant off flavor
6$^1/_2$	Definite but not unpleasant off flavor
6	Pronounced off flavor (slightly unpleasant)
5	Unpleasant off flavor
4	Definite unpleasant off flavor
3	Pronounced unpleasant off flavor
2	Repulsive flavor
1	Definite repulsive flavor
0	Pronounced repulsive flavor

Physical and Chemical Tests

All of the usual chemical tests applied to food products, such as moisture, fat, protein, ash, etc., are used to evaluate eggs and the methods employed are those outlined in the 8th edition of the AOAC "Official Methods of Analysis" (Anon. 1955). Tests of a more specialized nature or as adapted by cereal chemists for their particular needs can be found in "Cereal Laboratory Methods" (Anon. 1957). A number of additional tests are not considered official but are used commonly in the industry for evaluation. The most important of these is the standard whip test for frozen or dried egg whites. These tests are as follows:

Whip Test for Liquid Egg White.—Although the performance test of its "ultimate functional value" is the best answer to the whipping ability of whites, a test can be made by using 450 ml. of egg white in a 10-quart Hobart electric whipper. Whip the whites at speed two for 90 seconds and at speed three for 90 seconds. Remove the wire whip, level the foam and measure with ruler. Report whip in inches.

Whipping Test for Dried Albumen.—Dissolve 43 gm. of dried albumen in 430 ml. of water at 70°F. Using 10-quart Hobart Mixer, whip product 90 seconds at speed two and 90 seconds at speed three. Remove the wire whip, level the foam, and measure the depth with an ordinary ruler. Report whip in inches.

Color.—The determination of the natural color of eggs has long been an important problem to the baking industry. For some years the industry has been aware of the fact that the method employed, developed by the National Egg Products Association, was unsatisfactory. This was due primarily to the fact that an artificial standard of potassium dichromate was used in place of the true color reference. The Institute, through its Research Council, has developed a procedure for the determination of color in which results are reported as parts per million of β-carotene in the egg rather than the old artificial "NEPA" color grades. This new method is receiving acceptance, although there has been a reluctance on the part of the trade to change from the old procedure due to its common usage. The method given below has been subjected to collaborative testing (Forsythe 1958).

Method for Determination of Color.—Preparation of Standard Carotene Solution:

Prepare solutions containing 0.5, 1.0, 2.0, 3.0, 4.0, and 5.0 mmg β-carotene per ml. by weighing 0.24, 0.50, 1.0, 1.5, 2.0 and 2.5 gm. standard 0.05 per cent β-carotene in oil solution into a series of 250 ml. volumetric flasks, and diluting to volume with acetone. Solutions are stable at least one week in the dark. Equivalent amounts of standard β-carotene solution of different strengths may be used. Standard β-carotene solution in oil may be obtained from Vitamin Division, Hoffman-LaRoche, Nutley, N. J.

Preparation of a Standard Curve.—Determine the absorbance of diluted standard solutions as soon as possible using a spectrophotometer set at 450 mμ or an instrument having a suitable filter system such as the Klett photometer with No. 44 filter, Evelyn photoelectric colorimeter with 440 filter, or Cenco-Sanford-Sheard photometer, Industrial type B-2 with 410 filter. Plot mmg β-carotene against per cent transmittance, omitting values greater than 90 per cent or less than ten per cent, on semilog paper or against absorbance on plain coordinate paper.

Determination.—Weigh out a sample containing about one gram of egg yolk solids (1 gm. dried yolk, 2.5 gm. liquid yolk, or 5.0 gm. liquid whole egg) into a 150 ml. beaker. Add about 2.5 ml. acetone and stir to break up the lumps. Add about 2.5 ml. water before the acetone to products containing sugar or salt. Wash material onto Whatman No. 4 filter paper or equivalent with successive small portions of acetone, catching the filtrate in glass-stoppered 100 ml. volumetric flask. Dilute to volume with acetone. Determine per cent transmittance or absorbance as soon as possible. Calculate mmg β-carotene per gram of sample.

Insoluble Matter.—The presence of insoluble matter is of considerable importance to most users of egg products and the following tests are employed:

Stuart's Solubility Method.—Add 1.5 gm. of dried whole egg powder to 50 ml. of distilled water at 70° to 75°F. in a suitable size flask. Shake the contents of the flask vigorously to obtain a uniform dispersion and allow to stand for 30 minutes at room temperature. Shake the flask again vigorously (approximately 50 times). Filter through fluted filter paper (Whatman #12) and transfer to 5 ml. of the first 10 ml. of filtrate (using a volumetric pipette) to a 15 ml. tapered centrifuge tube, graduated in 0.1 ml. subdivisions. Add five ml. of 0.1 Molar sodium acetate buffer[1] pH 4.6 and sufficient distilled water to bring the contents to a final volume of 15 ml.[2] Transfer the tube to a boiling water bath for two minutes. Cool the tube and centrifuge at about 2000 r.p.m. for 6 minutes. Read the volume of centrifuged precipitate to the nearest 0.1 ml. graduation and record this reading as the "Stuart Solubility Index."

Per cent of Dried Albumen in Aqueous Solution.—Transfer 1.5 gram sample to 15 ml. centrifuge tube containing about 5 ml. distilled water.[3] Add 5 ml. distilled water and allow albumen to reconstitute completely with occasional stirring. Fill to mark, remove and wash stirring rod in process. Centrifuge at 2000 r.p.m. for 20 minutes. Pour off supernatant liquid and remix insolubles with additional distilled water. Fill to mark and centrifuge. Pour off supernatant liquid and wash insoluble matter into tared aluminum moisture dish and dry at 221° to 225° F. Cool and weigh. Calculate and report as per cent insolubles in the dried product.

One of the most important factors in alimentary pastes and products such as egg nog is the actual content of egg included in these products. Swanson (1957) includes a method for the analysis of the egg content of macaroni products by the determination of the cholesterol content which with appropriate factors can be converted to egg content. The determination of lipid phosphorus is used to determine the egg content of eggnog type products. Both of these tests, since they employ arbitrary conversion factors, are not too satisfactory but better techniques have not been developed.

Microbiological Tests

While in the past the baking industry has had little concern for the bacteriological qualities of the egg product, during the past decade the more progressive baking technologists have insisted on bacteriological specifications. All of the usual bacteriological analyses are carried out as described in the "Official Methods of Analysis" (Anon. 1955).

Determination of Salmonella.—A method for the enumeration of salmonella has been devised by a research committee of the Institute of American Poultry Industries and, although not available in published form, has received wide acceptance.

The salmonella are closely related to the coliform group but differ in that they (salmonella) do not ferment lactose and sucrose. Like the coliforms they are gram negative, non-spore forming rods.

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[1] The buffer solution is prepared by combining 102 ml. of 0.1 N Acetic acid, and 98 ml. of 0.1 N sodium acetate. The pH of the sodium acetate buffer must be frequently checked.

[2] 5 ml. of a 5 per cent NaCl solution may be substituted for distilled water, if coagulation is not complete at the end of two minutes in boiling water bath. This is in accordance with an unpublished letter of L. S. Stuart dated February 18th, 1943, a copy of which is on file at I. A. P. I. Laboratory.

[3] In the case of powdered albumen, transfer sample to dry centrifuge tube and mix with minimum amount of water to facilitate rehydration. Several drops of octyl (capryl-1) alcohol are recommended to inhibit foaming during reconstitution.

Materials and Apparatus.—

(1) six- to eight-ounce wide-mouth bottles
(2) screw cap (50 x 150 mm.) tubes
(3) wire racks for tubes
(4) Petri dishes
(5) salmonella polyvalent antisera
(6) selenite broth (or tetrathionate broth)
(7) bismuth sulfite agar
(8) brilliant green agar
(9) triple sugar iron agar

Presumptive[4] Procedure.—

(1) Weigh into each of three 6-oz. wide-mouth bottles, 10 gm. of sample and mark these three bottles "A."
(2) Weigh into each of three 6-oz. wide-mouth bottles 1 gm. of sample and mark these bottles "B."
(3) Weigh into each of three tubes 0.1 gm. of sample. If smaller samples are needed, prepare them from dilution as follows:

(a) 1 gm. sample – 99 ml. H_2O 1 ml. = 0.01/gm.
(b) 11 ml. of (1) – 99 ml. H_2O 1 ml. = 0.001/gm.
(c) 11 ml. of (2) – 99 ml. H_2O 1 ml. = 0.0001/gm.

(4) Add to the bottles containing the "A" and "B" series 99 ml. of selenite broth and to the remaining samples in the tubes 10 ml. of broth (for preparation of media follow manufacturer's instructions).
(5) Incubate the enrichments at 99°F. for 18 to 24 hours.
(6) After incubation of the enriched samples, invert to thoroughly mix the samples.
(7) Streak a loopful of each of the samples on prepared plates of brilliant green agar (B.G.A.) and bismuth sulfite agar (B.S.A.). Prepare these plates from dehydrated media (BBL) following the instructions on the bottle (each plate may be marked into three sectors and one sector used for each sample).
(8) Incubate the B.G.A. plates for 24 hours at 99°F. Any negative B.S.A. should be incubated for an additional 24 hours.
(9) Pick from these plates two or three suspicious well isolated colonies and transfer to triple sugar iron agar slants. Incubate 18 to 24 hours.
(10) After incubation slants showing acid and gas throughout the medium are discarded. Slants that exhibit a typical acid butt with or without gas and an alkaline slant are checked by use of Salmonella polyvalent serum and/or by susceptibility to the O–1 type bacteriophage as outlined by Cherry.

Serological Test with Polyvalent Serum.—Two procedures may be followed: the slide and the tube method. In the slide method the following procedure is followed:

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[4] This is a three-tube most probable number method adopted by the Institute of American Poultry Industries.

(1) A clean slide is placed on a horizontal colony counter or a specially constructed box with a glass top and an indirect source of light.
(2) Dilute the commercial polyvalent sera (Lederle) 1:3 with saline.
(3) Place one drop of saline on the slide.
(4) Place one drop of diluted antiserum on the slide near the saline drop.
(5) With a sterile loop transfer some of the growth from the triple sugar slants to the saline and mix.
(6) With the loop connect the saline culture mixture with the antiserum and mix.
(7) A salmonella should show agglutination within 30 seconds.

If the tube method is used add one drop of serum to the saline-culture suspension in 10x75 mm. tube—tilt tube and allow to run back down side of tube and read in indirect light for agglutination.

Calculation of Most Probable Numbers.—When the suspicious Salmonella colonies are tested with the antisera and a positive reaction occurs the tubes and plates are considered positive for Salmonella. This information is used in determining the most probable number of Salmonella per gram of sample.

(1) Determine the number of positive tubes in each of the series of enrichment tubes.
(2) Consult the MPN (Anon. 1934) and report as number of organisms per 100 g.

Functional Tests

As indicated above, no satisfactory functional tests have been developed or standardized throughout the industry. It has been necessary to rely on actual performance in the finished products produced by the baker. The extensive work that has been carried out in connection with the functional performance of flour and non-fat dry milk solids has not been applied satisfactorily to egg products. The wide variety of formulas for baked goods and the small quantity of egg used in most of them have made development of standardized techniques very difficult.

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CHAPTER 8

Samuel A. Matz

Minor Ingredients

In this chapter, the ingredients which are used in relatively small quantities in bakery foods will be discussed. It is only in the sense of quantity that they are "minor" components. In terms of their effects on the sensory qualities and physical characteristics of the product, they are frequently quite important ingredients—even indispensable.

Chemical leavening agents, although they might be considered to fall within the scope of this chapter, have been discussed in the chapter on formulations and procedures for chemically leavened bakery products. It was felt that continuity would be better served by this arrangement.

Some flavoring and coloring ingredients, such as citrus oils and extracts, vanilla, nuts and nut pastes, crystallized fruits, and food coloring preparations, and some substances used for their texture influencing properties, e.g., seaplant extractives, modified starches, and gelatin, are not discussed here because of space limitations. References to extensive treatises on some of these materials are given in the bibliography at the end of the chapter. Salt is discussed in the chapters on water and on yeast.

MALT PRODUCTS

Malt is prepared from a cereal grain, usually barley, by moistening it with water, allowing it to sprout under controlled conditions, and then drying it at elevated temperatures. Witt (1959) has given a detailed account of its manufacture. The natural processes accompanying sprouting create or release in active form large quantities of enzymes and change the constituents of the grain in many ways. The greatest consumption of malt is by the alcoholic beverage industries, but considerable quantities are used in milling and baking.

Malt products available to the baker may conveniently be classified as malt flour, malt syrup, or dried malt syrup. Each of these categories may be further subdivided into diastatic and non-diastatic products. Malt flour is the ground grain itself, malt syrups are concentrated water extracts of the grain, and dried malt syrups are derived from their liquid counterparts by removing most of the moisture at elevated temperatures.

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Non-diastatic Malt

Non-diastatic malt products have been subjected to temperatures high enough to inactivate substantially all of the amylolytic or starch-digesting enzymes present in the sprouted grain. These malts are used principally to impart flavor and color to baked products. They also have some effect on texture and supply fermentable carbohydrates and other nutrients to the yeast.

Non-diastatic malt products are high in sugars and low molecular weight dextrins which have been more or less caramelized by the high temperature processing which they have received. Consequently they can contribute a detectable amount of sweetness to products in which they are used. In addition, there is a peculiar and characteristic flavor to malt products which many people find very desirable. The use of malt in malted milk is a clear indication that there is a true liking for malt flavor in a large segment of the population. The color changes accompanying the caramelization and other non-enzymatic browning reactions which result from the high temperature processing make the product valuable as a coloring agent. It is frequently used to add color to dark rye breads and whole wheat breads. Special dietary breads may also make use of this property. On the other hand, use of high roasted malts in white bread is definitely limited by the darkening which is observed with moderate additions.

Both diastatic and non-diastatic malt contain considerable quantities of sugars including maltose, a disaccharide which is fermented by bakers' yeast late in the bread making process when glucose and fructose are absent, and glucose, a monosaccharide which is used very rapidly by fermenting yeast. If a dough does not contain maltose, the other fermentable sugars may be exhausted before the period of pan proof, a critical time when sustained gassing power is necessary in order to produce loaves having good volume. If maltose is present in the dough, either initially or through the action of amylolytic enzymes, the monosaccharides glucose and fructose (or sucrose, which is rapidly split into these monosaccharides by an enzyme present on the cell wall of yeast) are used first, then a lag period ensues, and finally the maltose is attacked leading to a final relatively rapid stage of gas production. This means that there is an inherent mechanism for assuring adequate gassing during pan proof if the doughs contain adequate maltose and the fermentation conditions are properly adjusted.

There are two ways of getting maltose into doughs. One method is to add the sugar to the dough in the form of malt, and the other is to rely on the production of maltose from the flour starch by diastatic enzymes. The latter approach is discussed in the next section.

Malt is fairly high in vitamins and essential amino acids and so is a nutritionally valuable additive. Table 59 gives a complete breakdown of the nutritive properties of malt flour. Malt syrup contains 60 to 65 per cent carbohydrate, 5.5 to 6 per cent protein, 1.5 per cent ash and 20 to 25 per cent moisture.

The minerals and low molecular weight nitrogenous compounds present in malt are said to be useful as yeast "nutrients."

Diastatic Malt

Diastatic malt products differ from their non-diastatic counterparts in having considerable enzymatic activity. The malted grain from which these products are derived is a veritable storehouse of enzymes, most of which have never been adequately investigated, but the only two types which are of importance to the baker are the proteolytic enzymes and the amylolytic enzymes. The latter group, comprising the "diastase" of the older writers, contains at least two different enzymes, commonly designated alpha-amylase or the dextrinizing enzyme, and beta-amylase or the saccharifying enzymes. Alpha-amylase splits the starch molecule at random points, forming smaller molecules of widely varying size. The net effect of this enzyme is to reduce the viscosity of susceptible starch suspensions with the production of relatively small amounts of fermentable sugars. End products of the reaction are chiefly dextrins (compounds containing several glucose residues) which cannot be used by bakers' yeast. There is some doubt that the amounts of alpha-amylase normally encountered in sound flour have any significant effect on its baking properties in the absence of native or added beta-amylase.

The action of beta-amylase on starch results in the production of maltose by the progressive release of terminal sugar residues from the starch molecule. This enzyme cannot attack the starch molecule inside the points at which it is branched, and so a residue of limit dextrin of high molecular weight remains. These limit dextrins cannot be fermented, but they are customarily produced in smaller amounts than the dextrins resulting from the action of alpha-amylase.

When the two types of amylases act in conjunction, a much greater conversion of starch into fermentable sugars results than when either of them acts alone. Alpha-amylase can act between the branch points which halt hydrolysis by beta-amylase. The new end groups exposed by this action are then subject to attack by beta-amylase. As a result, the amount of limit dextrin is decreased and the effective concentration of molecules capable of being hydrolyzed by beta-amylase is increased so that both the rate and the final yield is considerably increased in starch suspensions containing mixtures of the two enzymes. For example, the rapid and

TABLE 59

THE COMPOSITION OF BARLEY MALT FLOUR[1]

General Analysis	
Protein	11.5 to 14.5 per cent
Fat	1.5 to 2.5
Ash	2.0 to 3.0
Fiber	2.0 to 6.0
Nitrogen free extract	68.0 to 74.0
Composition of Fat	
Stearic acid	5.10 per cent of total fat
Oleic acid	16.40
Palmitic	8.20
Linoleic	49.40
Linolenic	0.82
Vitamin Content	
Biotin	0.1 mg. per lb.
Niacin	41. to 68
Pantothenic acid	2.0 to 7.8
Pyridoxin	2.7 to 3.6
Riboflavin	0.9 to 1.8
Thiamin	1.3 to 1.6
Choline	Present
Inositol	Present
Essential Amino Acid Content	
Arginine	0.65 per cent of malt
Histidine	0.29
Isoleucine	0.52
Leucine	0.81
Lysine	0.49
Methionine	0.18
Phenylalanine	0.62
Threonine	0.43
Tryptophan	0.22
Valine	0.70
Mineral Content	
Aluminum	2 to 9 p.p.m.
Calcium	0.08 to 0.13 per cent
Copper	4 to 12 p.p.m.
Fluorine	9 to 12 p.p.m.
Iodine	0.07 p.p.m.
Iron	20 to 50 p.p.m.
Magnesium	0.10 to 0.19 per cent
Manganese	10 to 18 p.p.m.
Nickel	0.34 p.p.m.
Phosphorus	0.30 to 0.50 per cent
Potassium	0.30 per cent
Silicon	0.20 to 0.90 per cent
Sodium	0.30 p.p.m.
Sulfur	0.13 to 0.22 per cent
Zinc	16 to 20 p.p.m.

[1] Courtesy Froedtert Malting Co.

relatively complete conversion of starch to fermentable sugars, typical of the action of malt, is a consequence of the combined action of alpha- and beta-amylase. Conversely, the slow rate of sugar development in unsupplemented flour suspensions or doughs results from a deficiency of these enzymes and particularly of beta-amylase.

The action of beta-amylase on undamaged starch granules is very slow. Alpha-amylase does attack the undamaged (no visible damage) starch granules at an appreciable rate. Both enzymes attack gelatinized starch very rapidly, but this reaction cannot be of much importance in the bread-making process because the starch in dough does not become gelatinized until virtually all of the enzyme activity has been destroyed by heat. Starch granules which have been mechanically damaged during milling are also broken down by both alpha- and beta-amylase. Perhaps 3 to 4 per cent of the starch granules in a hard wheat flour sample are visibly damaged. This mechanical damage is due to shearing forces and pressures exerted during the milling of the grain on the granules and on the endosperm matrix containing the granules. Consequently, the proportion of damaged granules is a function of the milling conditions, and may vary not only from mill to mill, but also between flours of different extractions. However, flours of similar extraction made from the same types of wheat and made at the same mill should have a rather constant proportion of damaged granules.

The capacity of malt to convert starch to reducing substances ("maltose") can be expressed as the Lintner value, °L., or as maltose equivalent. When tested by the standard procedure (Anon. 1957A), degrees Lintner equal about one-fourth of the maltose value. In each case, the rating of non-diastatic malt is theoretically zero, although in practice malts of 10°L. or less are classified as non-diastatic malt. A good barley malt flour might rate as high as 124°L. Diastatic malt syrups commercially available have ratings of 20, 40, or 60°L., and are described as low, medium, or high diastatic products, respectively.

The Federal Standards of Identity for bread (1952A) permit the use of non-diastatic malt syrup and dried malt syrup, and/or diastatic malt syrup, dried malt syrup, malted barley flour, and malted wheat flour in all varieties of bread and rolls covered by the standards. Maximum and minimum quantities of these ingredients are not specified.

Diastatic malt syrups are frequently recommended for use in bread formulas at the rate rate of 1 to 1$^1/_4$ pounds of syrup per hundredweight of flour. An excessive amount may darken the crumb, favor overfermentation, and promote the tendency of the dough to become sticky.

CACAO PRODUCTS

Chocolate is prepared from the seeds of an evergreen tree of the genus *Theobroma*. Several of these seeds are borne in a pod resembling somewhat a large acorn squash. After removing the seeds from the pod and fermenting them to facilitate the removal of the surrounding pulp (and to cause certain desirable flavor changes), they are dried or "cured." Next follows a roasting step which further develops the flavor and loosens the outer covering of the seeds. After the hull and the germ are removed by milling, the remainder of the seed, called the nib, is ready for processing into chocolate. The nibs are subjected to grinding and milling procedures which reduce the non-fatty substances to colloidal size and develop the texture which is characteristic of chocolate liquor, bitter chocolate, and bakers' chocolate.

Addition of milk solids and or sugar together with other flavoring materials such as vanilla, and sometimes emulsifiers, to chocolate liquor produces the "eating" chocolate varieties milk chocolate, sweet chocolate, and bittersweet chocolate. These products contain a minimum of 10, 15, and 35 per cent chocolate liquor, respectively. In Table 60 the composition of several cacao products is compared.

Cocoa is chocolate from which a substantial proportion of the fatty material has been removed. This is usually accomplished by pressing, but sometimes solvent extraction is used to remove a very large percentage of the cocoa butter. It is usually agreed that the best chocolate quality and flavor are contained in the liquor, especially when it has been produced from good quality Accra, Bahia, or Arriba beans. Off-grade and poorer beans such as Sanchez mid-crop, Lagos, and mid-crop Accra are frequently used to prepare the low priced cocoas of commerce. Cocoa from superior beans can be obtained readily, but it sells for a premium.

Even though chocolate liquor undoubtedly has a superior taste and aroma, cocoa performs quite adequately in most bakery foods. The advantages of chocolate liquor are much less evident here than in eating chocolate, and the price differential is such as to convince most bakers, even those who deal in top quality goods, that a good grade of cocoa is entirely adequate for their purposes.

Table 60

COMPOSITION OF PRODUCTS DERIVED FROM CACAO[1]

	Nibs, Roasted	Chocolate Liquor	Breakfast Cocoa	Cocoa, Medium fat	Dutched Breakfast Cocoa	Sweet Chocolate	Milk Chocolate	Chocolate Syrup
Moisture, per cent	3.0	2.3	3.9	4.0	5.0	1.4	1.1	31.0
Ash, per cent	2.8	3.2	5.0	5.5	8.0	1.4	1.7	1.9
Protein, per cent	10.5	8.0	8.0	8.7	7.7	4.0	6.0	3.5
Fat, per cent	55.0	55.0	23.8	16.0	21.5	33.0	33.5	1.1
Fiber, per cent	2.6	2.6	4.6	5.0	4.3	1.4	0.5	0.6
Alkaloids, per cent	1.45	1.4	1.9	2.1	2.0	0.4	0.4	
Carbohydrate,[2] per cent	25.2	26.6	44.3	48.7	40.2	61.3	55.2	56.0
pH	4.9	5.2-6.0	5.2-6.0	5.2-6.0	6.1-8.8	5.2-6.0	5.2-6.0	

[1] Anon. 1950.

[2] Other than fiber.

As stated above, the flavor quality of chocolate liquor is related to the type and origin of the bean, and the desirability of cocoas is related to the type of chocolate from which they were produced and to the per cent of fat which they contain. By Federal Standards (Anon. 1958), breakfast cocoa must contain a minimum of 22 per cent cocoa butter. Bakers frequently use a less expensive grade which contains from about 8 to about 15 per cent cocoa butter. Federal standards identify cocoa having less than ten per cent fat as "low-fat cocoa." In unpublished experiments by the author, it has been shown that consumer panels cannot differentiate significantly between cocoas of 14 and 18.5 per cent fat when they are used as the flavoring ingredient in devil's food cakes. This finding applies only to cocoas made from the same lot of nibs, of course.

Treatment of cocoa nibs with alkalies (such as potassium carbonate) at some stage during the roasting process profoundly changes their characteristics and gives the "Dutched" chocolates and cocoas of commerce. Some of the changes observed are: the color of the cocoa becomes darker, the flavor changes and becomes stronger; some of the cocoa butter is saponified; the starch is partially gelatinized; cellulose materials swell; the natural cocoa acids are neutralized and the slightly acidic pH changes to a nearly neutral or slightly alkaline pH; and, some of the tissues are disintegrated. The net changes of importance to the baking industry are the changes to color and flavor, which sometimes make it possible to use less of the flavoring material, and an increase in the solution stability of the product. The pH change can also create problems with the leavening system, since a decrease in soda or an increase in the acidic components of the batter or dough is necessary in order to maintain the hydrogen ion concentration at the desired level in the finished product.

Bakers using natural cocoa sometimes achieve a result similar to Dutching by increasing the final pH of devil's food cakes to rather high levels. The cocoa pigments assume a different color and the flavor changes under these conditions. The so-called mahogany color of a true devil's food cake is due to these reactions.

Federal specifications are frequently useful guides for establishing commercial requirements. The Federal specification for cocoa (Anon. 1952B) stipulates that breakfast type cocoa must contain at least 22 per cent cacao fat and medium-fat cocoa must contain from 10 to 22 per cent of cacao fat. Dutch process cocoas, according to this specification, shall have added alkaline materials (selected from among those permitted to be used for this purpose by the Food and Drug Administration) equivalent in neutralizing power to not more than 3 parts of anhydrous potassium carbonate per 100 parts of cocoa (sic) nibs from which the cocoa was made. All cocoas shall have a particle size such that 99 per cent of the cocoa shall pass through a No. 140 U. S. Standard Sieve after it (the cocoa) has been disintegrated and washed with petroleum benzine.

The Federal specification for chocolate and sweet chocolate (Anon.

1949) requires that bitter chocolate contain not less than 50 and not more than 58 per cent of cacao fat. Vanilla flavored sweet chocolate shall contain not less than 25 per cent of chocolate liquor together with the addition of such amounts of cacao butter as may be needed to give a smooth consistency with the amount of sugar used, the total fat being not less than 30 per cent. The total sucrose content shall not exceed 57 per cent and the product shall be flavored with vanilla, vanillin, or ethyl vanillin, and it may contain lecithin, phosphatides, and other stabilizers.

Many writers have published tables of correction factors to apply to the shortening percentage when cocoas of varying fat contents are used in the formula. Actually, cocoa butter is not a particularly good shortening agent and probably does not function in this capacity to any great extent in the usual formula. At any rate, the use of a universal correction factor for all types of bakery products is certain to lead to trouble. When a product containing cocoa is to be formulated, it should be developed in the usual thorough manner and not by calculations involving published correction factors.

DOUGH IMPROVERS AND YEAST FOODS

These products are usually mixtures of several inorganic salts together with starch or flour as an extender. Most of them contain ingredients having these functions:

(1) Gluten oxidizing agents such as potassium bromate, potassium iodate, or calcium peroxide; (2) Calcium salts, usually phosphates or sulfates, which correct any lack of hardness in the dough water and provide a certain small amount of additional buffering action to partially offset unusually alkaline conditions of the water; and (3) Ammonium salts to supply nitrogen in a form which can be used by yeast for protein building.

Some typical products are Arkady, Fermaloid, and Paniplus (these names are registered trade marks). On page 229 are some typical formulations for three different types of dough improvers.

Amounts of the first two types recommended for use in bread doughs are 0.25 per cent on the flour weight basis in straight doughs, and 0.5 per cent in sponge dough procedures. Type 3 is frequently used at the 0.25 to 0.50 per cent level.

Oxidizing Agents

Some of the effects which have been attributed to the proper use of added oxidizers in dough are larger volume, brighter crumb, better texture, and improved appearance of the finished loaf as a result of greater symmetry and darker crust. The oxidizers have little effect on gas production, they affect principally gas retention. However, there is some controversy

TYPE NO. 1

	Per cent
Calcium sulfate	24.93
Ammonium chloride	9.38
Potassium bromate	0.27
Sodium chloride	24.93
Starch and moisture	40.49

TYPE NO. 2

	Per cent
Potassium bromate	0.12
Potassium iodate	0.10
Ammonium sulfate	7.01
Sodium chloride	19.35
Monocalcium phosphate	50.06
Starch and moisture	23.36

TYPE NO. 3

	Per cent
Calcium peroxide	0.65
Diammonium phosphate	9.00
Dicalcium phosphate	90.00
Starch	0.35

about their exact mode of action although the majority of cereal chemists incline to the view that they exert their effect chiefly as a result of the oxidation of sulfhydryl groups on the proteins. According to this theory, the number of –S-S– bonds between protein chains is increased by the oxidizing action and a more tenacious network of molecules is formed. The gross result is a tougher, drier, more extensible dough which gives rise to loaves having the improved characteristics cited above. An extensive discussion of this theory was given in the Osborne Medal address of Sullivan (1948). An opposing theory, put forth with much vigor for several years, was that of Jørgensen (1939) who believed that the effect of oxidizers such as potassium bromate was due to their inhibition of proteolytic enzymes present in flour.

By far the most commonly used oxidizing chemical applied to doughs (as contrasted with the gases used by mills for this purpose) is potassium bromate. Calcium peroxide and potassium iodate are used to some extent. Each of these compounds affect dough somewhat differently. Potassium iodate begins its action earlier in the baking process than bromate. It also acts at higher pH levels and gives a somewhat drier dough with improved machinability. Bromate does not exert much influence during the mixing period but works later in the processing cycle to shorten the fermentation time, among other effects. Calcium peroxide gives drier and more pliable and elastic doughs which have a greater oven spring and can be taken with a somewhat shorter pan proof. It increases absorption considerably and should be incorporated at the dough stage.

Not all flours benefit from the addition of oxidizers. Well aged flour or flour which has been treated with optimum quantities of oxidizers at the mill may not show any beneficial results from use of dough improvers and may, in fact, give doughs and bread of inferior quality when supplemented in this manner. Flours which react best to supplementation are likely to be long extraction, freshly milled flours from wheats of generally good baking quality. Short extraction flours from poor varieties of wheat may not be improved at all by the addition of oxidizers.

Mills frequently add from 1 to 4 gm. of potassium bromate per 100 kg. of flour. As a general rule, supplemented flours are underbromated by the mills which use this oxidizer so that a safety factor is present. Neither potassium iodate nor calcium peroxide is used to any appreciable extent by the flour mills.

According to Kirk (1959), bromate can be used to overcome some of the deleterious effects resulting from overmalting, and from use of milks having poor baking quality. Conversely, a flour or dough to which an excess of bromate has been added can be improved by the addition of extra malt.

According to Doose and Wolter (1955), overtreatment of doughs with oxidizers can sometimes be recognized by appearance of ruptures on the dough surface at the end of the fermentation period. As a result, the dough becomes rough and uneven during molding. At extremely high levels of supplementation the proofing period is also extended, i.e. the dough is "bucky." Loaves made from overtreated doughs show irregular grain, a rough surface, reduced volume, and gray crumb color. Doose and Wolter state that larger amounts of bromate are called for when short fermentation time, low dough temperature, soft doughs, small additions of yeast, short times of kneading, or milk doughs are encountered. Smaller amounts of bromate should be added with long fermentation time, high dough temperatures, firm doughs, large additions of yeast, and intensive kneading. Remixing of overtreated doughs will usually completely eliminate the deleterious effects of the excess oxidizer.

Yeast Foods

The use of ammonium salts, phosphates, and sulfates in dough improvers and yeast foods is based on the hypothesis that these substances improve the fermentation capacity of yeast in doughs. It should be recognized at the outset of this discussion that the growth or reproduction of yeast in bread doughs has not been shown to be either a necessary or a desirable accompaniment of the development of flavor or gas. Bakers' yeast as ordinarily supplied to the trade consists of very healthy, vigorous cells which can readily ferment at nearly the same rate throughout the entire dough processing cycle. If the gassing power is shown to be inadequate due to an insufficient supply of yeast at any stage, the proper remedy is to add more yeast, not to try to grow yeast in the dough.

Atkin *et al.* (1946) have shown that some of the substances commonly considered to be necessary for growth also have an accelerating effect on the gas production of yeast fermenting in artificial media. Potassium, magnesium, ammonium, sulfate, and phosphate are the principal inorganic ions found to be required. Vitamin B_1, thiamin, also can markedly increase the rate of fermentation. As these authors point out, most, if not all, of the accelerating substances are present in doughs in sufficient amounts to support fermentation at optimum rates. For example, they state:

> (1) "It is therefore probable that the phosphate content of flour is ordinarily sufficient to maintain yeast at its maximal fermentation rate, provided all other factors are present in adequate amount"; (2) "It seems probable from these data that sulfate, in adequate amount, is present in white flour"; (3) "As with phosphorus and magnesium, there is evidence that flour contains sufficient quantities of potassium and hence conceivably could make available adequate amounts for the nutrition of yeast"; and (4) "Although a large proportion of the thiamin of the wheat berry is removed in the course of the milling process which produces white flour, the amount retained is sufficient to exert maximal acceleration in most cases."

Minerals and Buffers

The effect of the cations of water on dough quality has been explained in some detail in the preceding chapters on water and yeast. If water is very low in such ions as calcium, the gluten may be adversely affected with resultant poor dough quality. Use of some of the salts which are included in most dough improvers is indicated in such cases. After an optimum level of concentration is reached, further additions have little effect.

If the water supply is alkaline, the buffering action of some of the salts used in dough improvers may bring the pH down slightly. Considering the small amounts of these substances which are customarily added to doughs, it is difficult to see how the effect could be very pronounced.

INHIBITORS OF MICROBIOLOGICAL SPOILAGE

The only form of microbiological spoilage with which the average baker has to contend is mold growth. A few decades ago, rope caused by *Ba-*

cillus mesentericus or similar organisms, was a serious problem, but today's improved sanitary practices in the bakery combined with rapid turnover of the finished product have virtually eliminated this form of spoilage. Many bakers in the United States have never seen a true case of rope. Mold spoilage still remains a problem, however. No feasible amount of sanitation can prevent contamination of bakery products with the ubiquitous mold spores, and an abundant growth of mycelia and sporangia can appear on a loaf within three days if the conditions of humidity and temperature are right.

Over the years, a considerable number of chemical compounds have been proposed as fungicides or fungistats for use on, or in, food substances. Most of these materials are no longer heard of because they were shown to be either toxic to man or innocuous to molds—frequently both. However, the sodium and calcium salts of propionic acid and sodium diacetate have been used with good results for some time. Most of the organic acids having carbon chain lengths of 1 to 14 exert some fungistatic action but various objections, including that of inadequate supply have limited commercial applications of all but the two and three carbon compounds. It is the acid moiety of these substances which is effective, use of the salts being merely a convenience. However, some authorities have claimed that mixed salts have greater effectiveness than the combined acids.

According to the Food and Drug Administration (Anon. 1952A), white, enriched, or raisin bread and rolls covered by the Standards of Identity may contain not more than 0.32 per cent calcium propionate or sodium propionate (or a mixture) on the flour weight basis provided the label includes a statement that the compound has been "added to prevent spoilage." Whole wheat or graham bread and rolls may contain as much as 0.38 per cent of the compounds on the basis of the whole wheat flour used as 100 per cent.

Many persons claim that they can detect by odor or taste the presence of propionic acid in baked products, even when it is present in the small concentrations permitted by the Federal government.

ENZYME PREPARATIONS

Fungal Proteases

Fungal protease acts on dough by breaking down the flour proteins. A "mellowing" effect on the dough results. Mixing requirements of strong flours used in sponges can be considerably reduced when proteases are used. These enzymes also increase the extensibility of doughs and thus are of value in controlling the pliability, eliminating buckiness, and insuring proper machinability. In many cases, it is possible to eliminate these difficulties without resort to added enzymes through changes in processing conditions, absorption, etc. It is also claimed that proteases can improve the symmetry, grain, and texture of the loaf and increase the compressibility of bread crumb.

The fungus *Aspergillus oryzae* is usually employed for production of proteases for the baking industry. The mold is grown in a liquid medium which contains the necessary nutrients. As it grows, the mold excretes into the medium many enzymes, among them the desired protein digesting catalysts. After a time, the solid material is removed by filtration or centrifugation, and a mixture of organic compounds including the proteases is precipitated from the liquid as a result of the addition of some solvent such as ethyl alcohol or of inorganic salts. Usually, no further purification of the precipitate is attempted, and drying, and sometimes standardization by adding inert fillers, are the only remaining steps before the enzyme preparation is packaged. For retail sale, the proteases are frequently made into tablets of standardized activity. The "strength" of the preparation is commonly expressed in terms of hemoglobin units. These indicate the rate of hydrolysis (or solubilization) of hemoglobin, which is a convenient standard substrate. A potent precipitate may exhibit an activity of 100,000 or more hemoglobin units (H. U.) per gram. Dilutions offered to the bakery trade often have an activity of about 300 H. U. per gram with a suggested rate of usage of 4 oz. per 100 lbs. of flour.

Salt inhibits the action of fungal proteolytic enzymes on gluten, so that their effect on straight doughs containing about two per cent of salt is negligible. When active dry yeast is used as the leavening agent, proteases are not normally employed since the yeast itself has a mellowing effect on the dough (Reed and Thorn 1957).

Fungal Amylases

These enzymes are distributed as replacements for the amylolytic enzymes of diastatic malt. They provide a means of adding necessary starch digesting properties to a dough without also adding the flavor and color of malt. In general, the fungal preparations are also cheaper per unit of activity than malt. On the other hand, they do not have the nutritive quality of grain preparations, and in many cases the flavor and color of malt is desirable. The general discussion of the net effect of malt diastase on dough properties is also applicable to fungal amylases.

Enzymatically Active Soy Flour Derivatives

Enzymatically active soy flour is used extensively in the commercial preparation of white bread. The enzymes chiefly concerned are the lipoxidases, although proteinases and beta-amylase play a minor role. Alpha-amylase is absent.

Lipoxidases in bread dough have three functions:

(1) Bleaching of the carotenoid pigments with the result that whiter bread may be obtained with both unbleached and bleached flours (bleached flour usually contains a substantial amount of carotenoid pigments).

(2) Influencing dough properties; frequently this is the most important function. Doughs containing lipoxidases possess what bakers term greater "mixing tolerance" and dough extensibility, which means that they can be mixed longer and machined without damaging the rheological properties required to make good bread. The improvement in mixing tolerance can be demonstrated by the farinograph, and improvement in dough extensibility may be observed readily by the experienced baker during various stages of bread making.

(3) Contributing bread flavor. The soybean contains at least two lipoxidases, one active chiefly on triglycerides and the other on fatty acids (Koch *et al.* 1958). Research in recent years has shown that the lipoxidases promote the oxidation of gluten, strengthening and improving dough properties. The effect on dough properties is thought to be the result of lipoxidase action on the lipo-protein complexes of flour. The latter apparently are connected with bread volume, crumb firmness, grain and texture. Because dough properties are improved by soy enzymes, bread quality is also enhanced. Among the improvements obtained are finer grain, softer texture and retardation of staling.

The beta-amylase of soy flour is unique in that it has greater heat stability than the beta-amylase of wheat and barley. Thus, sugars are produced from starch by soy beta-amylase for a considerable time after wheat and barley beta-amylase are heat inactivated. For baking procedures which exhaust sugars during fermentation, this action will contribute to a better crust color and to a more vigorous fermentation at the end of the baking process.

Two types of product containing enzymatically active soy flour are available to the commercial baker. One type consists of soy flour with partially dextrinized corn flour or other cereal flours or starches. A second type contains, in addition to soy flour, calcium peroxide and sometimes phosphates. The latter type of product is used principally for the well-known calcium peroxide effect, which is to increase water absorption and to form drier, less extensible doughs. The effect of lipoxidase here is superimposed on the calcium peroxide effect and desirable dough extensibility is restored without impairing water absorption.

The product called Wytase contains full-fat, enzymatically active soy flour and dextrinized corn flour. Enzyme activity is standardized at a level which requires optimum usage at the rate of one per cent based on the flour. The corn flour fraction is prepared from purified corn grits, heat dextrinized under controlled conditions to provide uniform water absorption, which is a satisfactory measure of the degree of conversion of the starch. The corn flour fraction thus modified contributes to water absorption and bread yield. It also provides a more readily available substrate for amylase activity than unmodified starches do. Doughs made with one per cent Wytase will normally require one per cent additional water.

Depending somewhat on the quantity of enzymatically active soy flour used in the bread formula and also on the quality of some of the other ingredients, especially shortening and milk solids, bread will have a pleasing flavor regarded by many to be the most important reason for using a product of this type. Recent work on bread flavor suggests that the lipoxidases initiate mild reactions of the fatty components of a bread dough, and these are sufficient to produce minute quantities of cleavage products of the aldehyde type which contribute pleasant notes to bread flavor. Much of the bread produced commercially is made by procedures which result in extreme blandness, for which reason the enhancement of flavor by soy enzymes assumes some importance (Ferrari 1959).

SPICES

Fresh, high quality spices offer innumerable ways for a baker to introduce variety to this line. Each spice is imported from several different sources and the quality will vary accordingly, as shown in the following discussions. The most sensible buying procedure is to make sure that the supplier is reputable and to take the attitude that quality is more important than minor price differentials. The few pennies difference between grades is not worth the chance of failure in flavoring, especially in quantities usually baked in commercial operations. Store all spices in a cool, airy, and dry room. Limits of storage life have not been defined but it is certain that it is never wise for a baker to speculate with these aromatic ingredients. Buy only according to current needs and make sure the containers are tightly covered when not in use since their volatile oils will escape on lengthy exposure to the air.

For those buyers wishing to check the quality of their spice purchases, the American Spice Trade Association, 82 Wall Street, New York 5, N. Y. makes available a series of methods for spice analysis. Included are procedures for testing volatile and non-volatile oils, total ash, starch, crude fiber, etc. The entire set of 11 methods is priced at $1.24 per single order or $1.00 per set plus postage on orders of more than one.

Cinnamon

Cinnamon, our most important baking spice, comes from the bark of an evergreen tree. The member of the cinnamon family most used in the United States is *Cinnamonum cassia*, which in spice trade vernacular is usually shortened to cassia. This plant is native to China, Indo-China, and Indonesia. There is another member of the clan that goes under the term cinnamon also. This is *Cinnamonum zeylanicum*, or Ceylon cinnamon. It is quite different in color, texture, and flavor strength from cassia and very little is used here, but it is popular in Mexico and in Europe. There are three varieties of cassia in commerce today—Saigon cassia, Batavia cassia, and Korintje cassia. Saigon is a product of Indo-China while Batavia and Korintje are both Indonesian cassias. Imports from China have been non-existent since the United States embargo on communist goods.

Saigon Cassia.—This is considered to be the finest cassia a baker can use. It comes from a bark that is greyish brown on the outside and reddish brown underneath. As a result, ground Saigon is slightly lighter in color (sometimes even greyish brown) than either Batavia or Korintje cassias, which have an even reddish brown color throughout.

Cassia bark is slit and stripped off young trees and rolled into "quills" (commonly called "cinnamon sticks"). As they arrive in the U. S. these quills are from 2 to 3 feet long. Saigon quills are graded according to thickness of bark: thin, medium, and thick. A certain proportion of Saigon also comes in as "broken stick," graded no. 1 and no. 2. Thin quill Saigon is recognized as the prime quality because the thin bark from the small twigs of the tree has a higher volatile oil content and finer quality of flavor. Buyers should understand that the term "thin quill" is not merely descriptive of good cassia, but is a specific grade.

Korintje Cassia.—This product comes from Sumatra and adjacent islands, including one by the name of Korintje. The bark is thick, in general, and dark reddish brown in color. There are two grades, "A" and "C," the "A" being the thinner and more highly flavored of the two. Though it is not as aromatic or as intensely flavored as the Saigons, Korintje is considered a good cassia.

Batavia Cassia.—This is from the same general area as Korintje, but is characteristically a product of the lowlands whereas Korintje comes mostly from the uplands. It is sometimes known as Padang cassia. The bark is usually thinner than Korintje and it has a somewhat lighter color. The flavor is not as strong as either the Korintjes or the Saigons and as a result, Batavia is normally the lowest priced. If Batavia cassia is mixed with water before it is added to the flour, there is danger that it will form a mucilaginous mass which can prevent a smooth blending of the other ingredients.

Cassia yields from 0.5 to 5 per cent volatile oil having the following characteristics:

Specific gravity at 59°F.: 1.055 to 1.072
Optical rotation at 68°F.: +6° to −1°
Refractive index at 68°F.: 1.585 to 1.606
Principal constituent: Cinnamic aldehyde (75 to 95 per cent)
Solubility: 1 part in 2 parts of 80 per cent alcohol.

In baking, cinnamon is used in the doughs, fillings, and icings of buns, cakes, cookies, and pies; fruit toppings; dry toppings; and custards. It is compatible with the flavors of sugar, chocolate, coffee, apple, peach, and pear. One ounce of the ground spice is equivalent to about 17$^1/_2$ teaspoonfuls.

Nutmeg

This spice is the seed of a peach-like fruit of a tropical evergreen tree. The seed is ovular in shape and ranges in size up to 1$^1/_4$ inches in length. Although it is native to the Molucca Islands, it is imported mostly from Indonesia and the West Indies today. The two principal grades are "East Indies" and "West Indies." They are graded large, medium, and small according to the number per pound. Large average 60 to 75; medium, 90; small, 100 to 110. East Indian nutmegs usually have a slightly higher oil content and thus command a higher price.

Nutmeg yields from 7 to 15 per cent of volatile oil having the following properties:

Specific gravity at 59°F.: 0.865 to 0.930
Optical rotation at 78°F.: +10° to +30°
Refractive index at 78°F.: 1.475 to 1.489

One part of the oil is soluble in three parts of 90 per cent alcohol.

In baking, this spice is frequently used in: doughnuts, doughs of spice and butter cakes, pastry crusts, and dry toppings for custard pastry. It is compatible with sugar, apple, cherry, peach, pear, and coffee flavors. When in the common granulation, 12$^3/_4$ teaspoonfuls of the spice equal one ounce.

Mace

The fleshy aril or skin which surrounds the nutmeg (seed) inside the nutmeg fruit is also a spice. The entire fruit looks something like a small peach. The outer layer, however, is a thick husk inside of which is the lacy mace layer surrounding the seed. Major sources are, of course, the same as for nutmeg, i.e. Indonesia and the West Indies. When harvested the mace is a vivid red, but this changes to a light orange after drying. It is sold as East or West Indies, no. 1 or no. 2, according to color and quality.

Mace yields 7 to 14 per cent of volatile oil which closely resembles oil of nutmeg. It has the following properties:

Specific gravity at 59°F.: 0.890 to 0.930
Optical rotation at 78°F.: +10° to +20°
Refractive index at 78°F.: 1.476 to 1.480

One part of the oil is soluble in three parts of 90 per cent alcohol.

The spice is used in basic sweet dough, sponge and pound cakes, cream fillings for eclairs and charlottes, and cherry pie filling. It is compatible with sugar, custard, and cherry flavors, among others. Fourteen teaspoonfuls of the spice equal one ounce.

Cloves

This spice is the dried, unopened buds of an evergreen tree native to the Molucca islands, now a part of Indonesia. Today we import most of our cloves from Zanzibar and Madagascar. Either of these sources can produce excellent cloves so that grades are not so much a matter of origin as of individual quality.

Cloves contain a high percentage of non-volatile penetrating oil and so should not be stored for long in fiber or paper containers lest the oil soak through. This oil, present in amounts of 14 to 21 per cent of the spice, has the following properties:

Specific gravity at 59°F.: 1.044 to 1.069
Optical rotation at 68°F.: 0° to −2°
Refractive index at 77°F.: 1.528 to 1.540
Principal constituent: Eugenol (80 to 95 per cent)

The principal baking uses of the spice are in doughs for spice cakes and cookies, fruit fillings, hot breads, and fruit cakes. It is compatible with sugar, most stewed or preserved fruits, and pumpkin. Fourteen and one-fourth teaspoonfuls of the spice weigh about one ounce avoirdupois.

Ginger

Ginger is the root, or rhizome, of a tuberous perennial plant of the tropics. It is native to southern Asia but today is imported from Jamaica, India, and Africa. After harvesting, the roots are separated into small pieces that in the trade are called "hands" of ginger. Jamaican ginger is traditionally rated as top grade, primarily because of its appearance. In Jamaica the ginger is peeled after harvesting and the resultant product is lighter in color and considered to be smoother in flavor. However, Cochin ginger, the product of the State of Cochin in India, is an excellent grade for baking. African ginger, the lowest priced of the three, has a harsher flavor, but would be suitable for something like gingersnaps where strength is considered a virtue.

Ginger yields from 1 to 3 per cent of volatile oil having the following properties:

Specific gravity at 59°F.: 0.872 to 0.886
Optical rotation at 68°F.: —25° to —45°
Refractive index at 68°F.: 1.478 to 1.495

One part of the oil is soluble in three parts of 70 per cent alcohol.

Bakers use the spice in gingerbread and doughs for cakes, cookies, wafers, and pies. The flavor is compatible with sugar, orange, pear, and pumpkin. Fourteen teaspoonfuls of the ground spice weigh about one ounce.

Allspice

This substance is the dried, nearly ripe, pea-sized fruit of an evergreen tree. It is native to the Western hemisphere and today is imported from Jamaica, Mexico, Guatemala, and other parts of Central and South America. It takes its name from the resemblance of its flavor to a blend of cloves, cinnamon, and nutmeg. However, the predominant flavor is that of cloves. Jamaican allspice is considered the best quality. The products of the other sources are rated more or less equal to each other at a level below the Jamaican variety. The buyer should make sure that the source is specified.

Allspice contains 3 to 4.5 per cent of a volatile oil having the following properties:

Specific gravity at 59°F.: 1.025 to 1.055
Optical rotation at 68°F.: 0° to —5°
Refractive index at 77°F.: 1.525 to 1.535
Principal constituent: Eugenol (60 to 80 per cent)

One part of the oil is soluble in two parts of 70 per cent ethyl alcohol.

Its baking uses are in doughs for spice cakes and cookies, in pies and tarts, and in fruitcake. The flavor can be used in conjunction with sugar, blueberry, pineapple, pear, and apple flavors. Fourteen teaspoonfuls of allspice will weigh about one ounce.

Cardamom Seed

Cardamom seed is the dried fruit of a plant of the ginger family. It is native to India, and today we import it mostly from India, Guatemala, and Ceylon. The reddish-brown seeds are contained in a fibrous capsule (from 8 to 16 seeds per capsule) which may be either greenish-brown in color or a creamy white if it has been bleached. For pickling and similar uses the whole pods are available, but if the seeds are to be ground as for use in baking, decorticated cardamom (seeds removed from the pods) is specified. Guatemalan and Indian cardamom rank about equal in quality.

The oil in cardamom represents about 3.5 to 8 per cent of the seed weight, and has the following properties:

Specific gravity at 59°F.: 0.922 to 0.950
Optical rotation at 68°F.: +22° to +40°
Refractive index at 68°F.: 1.460 to 1.470

Cardamom is suitable for flavoring Danish pastry, fillings for eclairs and cream puffs, and pies. It is compatible with sugar, blueberry, grape, apple, and pumpkin flavors. One ounce equals 14¼ teaspoonfuls of the spice.

Poppy Seed

These are the tiny seeds of an annual of the poppy family. The plants are native to Asia but today we import most of our supply from the Netherlands, Poland, Argentina, and Iran. Blue poppy seed, a type made famous by the Dutch, is considered the highest quality because it can be used for garnish as well as for flavor. Blue poppy seed is actually a slate blue color. Because of its very high oil content, poppy seed cannot be powdered and therefore is not sold except as the whole seed. For fillings where a smooth texture and the rich, nutty flavor of the seed is desired, it is possible to buy ground poppy seed that has been mixed with honey. While these seeds do come from the poppy plant, they have no narcotic properties.

Poppy seeds do not contain essential oils. They do contain a fixed oil in amounts of from 50 to 60 per cent.

The seeds are used as toppings for breads, rolls, and crackers, fillings for coffee cakes, strudels, and other pastries, and sometimes in cakes. Eleven and one-fourth teaspoonfuls of seeds weigh one ounce.

Caraway Seed

This spice is the fruit of a biennial of the parsley family, native to Europe. It is imported mostly from the Netherlands and Poland. Netherlands caraway is recognized as top grade. For the bakery trade, caraway is available ground as well as whole. This true caraway has no relationship to the "charcoal caraway" or "black caraway," a small black seed that is used mainly for toppings on breads of central European and Russian origin.

Caraway yields from 3 to 7 per cent of volatile oil having the following properties:

Specific gravity at 59°F.: 0.907 to 0.920
Optical rotation at 68°F.: +70° to +82° (usually +75° to +78°)
Refractive index at 77°F.: 1.484 to 1.497
Principal constituent: Carvone (50 to 60 per cent)

One part of the oil will dissolve in ten parts of 80 per cent alcohol.

Caraway is almost indispensible in the making of rye bread, and it is also good in corn muffins, cheese rolls, and certain kinds of cakes and cookies. It is compatible with the flavors of sugar, apple, peach, apricot, and rye.

One ounce of the spice equals $9^1/_2$ teaspoonfuls.

Anise Seed

The fruit of a small annual plant of the parsley family, when dried, becomes the spice anise. It is oval in shape, somewhat like caraway, but is greenish-brown in color. It is native to Egypt but most of our present supply comes from Spain, Mexico, and Turkey. Quality of the spice from each source is about the same. The flavor is recognized by most people as licorice. Very similar in flavor, but botanically unrelated, is star anise, a small star-shaped cluster of seeds. Star anise was formerly imported from China and has not been available since the embargo on communist goods.

The essential oil in anise seed is present in amounts of 2 to 3 per cent and has the following characteristics:

Specific gravity at 68°F.: 0.975 to 0.990
Optical rotation at 68°F.: 0° to —2°
Refractive index at 77°F.: 1.552 to 1.558
Principal constituent: Anethole (80 to 90 per cent)

In baking, anise seed is used in icings and fillings for cakes and cookies, and toppings for coffee cakes and sweet rolls. It is compatible with sugar and most stewed fruits.

Material for the spice section was supplied by Marshall W. Neale of the American Spice Trade Association. Analytical values were adapted from those in The Chemists' Yearbook.

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SECTION II

Formulations and Procedures

CHAPTER 9

Samuel A. Matz

Formulations and Procedures for Yeast-Leavened Bakery Foods

There are probably innumerable schemes for classifying bakery products, but the most sensible way to categorize them for the bakery engineer or cereal chemist would seem to be on the basis of the source of leavening gas. There is not much overlap between the various classes when this procedure is used, and it will be found that a host of characteristics and many of the processing techniques vary in association with the type of leavening system. It is this scheme which has been followed in organizing the second section of "Bakery Technology and Engineering."

Yeast-leavened products include not only those foods in which yeast serves principally as an aerating agent but also those in which the leavening action is secondary in importance to the functions of dough conditioning and flavor-developing. Examples of the latter types are Danish pastry and soda crackers. Some leavening action is unavoidable when live yeast is included in a formulation since gas production by the organism is continuous in the presence of substrate (assuming the yeast is fully adapted to the substrate) and it would be difficult to formulate a dough which did not contain some carbohydrate which the yeast could utilize. In fact, yeast of the kind used by bakers has a detectable endogenous gas production rate.

Some products in both groups, i.e. foods in which yeast is included primarily for its leavening action and foods in which the desired functions are other than gas production, will be discussed in this chapter, but primary emphasis will be placed on products such as bread where the leavening function is paramount, since the principles involved are also applicable to the other group.

The chapter was planned so as to present first some general considerations regarding the products, next to present some examples of formulas and procedures for the principal types of products and finally to discuss some common defects and their causes. The initial discussion will deal with the sequence of reactions occurring in fermenting and baking doughs, and the function of the most important ingredients and processing steps. Actual recipes and preparation methods will follow, and, finally, some "trouble-shooting" hints will be listed.

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FUNCTIONS OF THE PRINCIPAL INGREDIENTS AND PROCESSING STEPS

Yeast provides flavoring compounds, affects the texture of the dough and baked product, and supplies carbon dioxide which decreases the density of the food.

As yeast ferments the sugars in dough, it releases to the surrounding liquid dissolved carbon dioxide and ethanol, and metabolic by-products such as lactic acid, acetic acid, etc., as well as small quantities of unknown compounds. Bakers' yeast cannot hydrolyze proteins or even peptides and so in its intact form exerts no proteolytic effect on gluten. It cannot attack starch or dextrins and so does not affect dough viscosity by breaking down these compounds of large molecular weight. However, the acids such as lactic and acetic, which yeast elaborates, have a definite effect on some of the gluten proteins that is best described as a solubilizing action. The net observable effect is a mellowing or weakening of the dough structure.

Carbon dioxide passes through the yeast wall as a dissolved compound, probably in the form of bicarbonate ion. As the concentration of carbon dioxide increases in the free liquid outside the cell, gas bubbles begin to form around foci in the dough. These foci have never been clearly identified although very possibly they may be small air bubbles incorporated into the dough during mixing. It appears certain that the foci are not the yeast cells themselves. The importance of this point is that fineness of grain, i.e., the number of gas vesicles in a given volume of bread, is not entirely controlled by the number of yeast cells present, and that uniformity of grain is not governed solely by the uniformity of yeast cell activity. These product qualities must be controlled by other methods and are usually determined in practice by the physical treatment accorded the dough, especially during mixing.

The substances contributing the major portion of the characteristic aroma of bread and similar foods undoubtedly arise either directly or indirectly from the activity of yeast. The responsible chemicals are mostly unknown, but it is to be hoped that the techniques of gas chromatography will enable investigators to identify most of them within the next few years. The substances are probably mostly extra-cellular. A simple proof of the latter statement can be obtained by baking a dough which contains yeast cells that have been washed to remove the extra-cellular metabolic by-products and then killed by heat. The odor of the baked product is not like that of bread. Furthermore, it is probably better to call the substances produced by yeast bread flavor precursors rather than bread flavors. It is a common enough observation that a well fermented dough does not have a bread-like smell, yet the same dough subjected to the baking process will yield during the later stages the characteristic and appealing odor of bread. It is the author's belief that the actual odorant compounds are created in or near the region of the crust as a result of non-enzymatic browning reactions. Participants in this reaction would be some of the unknown extra-cellular metabolites of yeast and nitrogenous substances originating mostly from the flour. The author has shown that fermentation broths from which the cells have been removed are potent contributors of bread-like flavors to chemically-leavened baked goods. The flavor precursors in broth are subject to rapid deterioration at elevated temperatures or if access to oxygen is facilitated. They can be preserved to a limited extent by freeze-drying the broth.

When yeast cells reach about 140°F., as they do shortly after baking commences, the semi-permeability of the cell membrane is destroyed. As a result, the low molecular weight compounds in the cytoplasm may diffuse out through the cell wall. These substances may have a definite effect on the characteristics of the product since the gluten is not coagulated at this temperature and the vesicle walls are still extending as the heat continues to expand the contained gases. The effect of these reactions has never been adequately investigated, but purely qualitative observations would lead one to believe that the net result is an increase in the extensibility of the vesicle wall. Such compounds as reduced glutathione, known to be extractable from heat-killed yeast, might have such an effect.

The peculiar property of wheat flours which makes them indispensable for the preparation of light, well-aerated foods such as bread is the ability of the gluten proteins to form very thin continuous films which are rather impervious to carbon dioxide and moisture vapor diffusion. These films form the walls of the gas vesicles. In them are embedded the starch granules and other particulate masses which are completely surrounded by the thin layer of hydrated protein. On the molecular level, the gluten films are probably composed of networks of protein molecules bound to each other by relatively strong ionic bonds such as —S—S— and by weaker hydrogen bonds, and surrounded by vast numbers of water molecules bound by forces of varying but relatively low strength. The water molecules undergo constant exchange with the "free" water which dissolves the sugars and other soluble dough constituents.

The dissolved gas emitted by the fermenting yeast cells eventually supersaturates the free water to an increasing distance from the cell until finally a discontinuity of some sort in the medium causes evolution of part of the dissolved gas at a restricted locus. The evolved gas forms a bubble in the gluten film which continually enlarges as further carbon dioxide diffuses into the open space. If this process were allowed to continue without interference, the dough would contain few vesicles and all would have thick walls. The mechanical punishment to which the dough is subjected at various stages in the processing procedure subdivides the bubbles, increasing their number and decreasing their size. Although most of the vesicle walls are ruptured by the pressing and beating steps, the breaks are quickly sealed as a result of the elasticity and cohesiveness of the gluten.

PROCEDURES AND FORMULATIONS FOR BREADS AND ROLLS

Limitations on the establishment of procedures and formulations for yeast-leavened bakery products are the result of both legal and technical considerations. The legal limitations arise from the provisions of the Federal Definitions and Standards for Bakery Products (Anon. 1952) which set forth requirements for white bread, enriched bread, milk bread, raisin bread, whole wheat bread and the equivalent rolls and buns. The technical limitations are due to the inherent characteristics and the interactions of the ingredients and the processing techniques which may be employed in the manufacture of the products.

The limitations established by the Federal Definitions and Standards are, in general, quite lenient with respect to the types and relative proportions of flour, sugar, shortening, yeast, and salt which can be used. The only processing requirement is that the products be prepared by "baking a kneaded yeast-leavened dough." Although this latter limitation seems extremely easy to comply with, it does exclude any product leavened wholly by chemical agents.

Permissible ingredients for white bread are: flour, including bromated flour and phosphated flour; yeast; water, or an optional liquid ingredient, salt; shortening, including certain specified emulsifier additives; milk or milk products in quantities less than necessary to qualify the bread as milk bread; certain milk derivatives such as buttermilk, cheese whey, milk proteins, etc.; eggs, egg yolks, and egg whites; sugar, invert sugar, light colored brown sugar, honey, corn syrup, etc.; malted cereals and preparations made from malted cereals; inactive dried *Saccharomyces cerevisiae* in quantities of not more than two per cent of the flour used, harmless lactic-acid producing bacteria; corn flour, potato flour, rice flour, certain starches, or soy flour in quantities equalling not more than three per cent of the flour used; ground de-hulled soybeans, optionally defatted, in quantities of not more than 0.5 per cent of the flour used, calcium sulfate, calcium lactate, calcium carbonate, dicalcium phosphate, ammonium phosphates, ammonium sulfate, or ammonium chloride in quantities not to exceed 0.25 parts for each 100 parts by weight of flour used; potassium bromate, potassium iodate or calcium peroxide in quantities not exceeding 0.0075 per cent of the flour; monocalcium phosphate up to 0.75 per cent of the flour; vinegar, not more than 1 pint of 100-grain vinegar per 100 pounds flour; calcium propionate, sodium propionate, or any mixture of them in quantities totalling not more than 0.32 parts per 100 parts by weight of flour; sodium diacetate, not more than 0.4 parts per 100 parts of flour; lactic acid in amounts sufficient to bring the pH of the finished bread to pH 4.5 or above; and spice, spice oils, and spice extracts. In some cases, label declarations of some of the optional ingredients is required. In addition, the total solids of bread must be at least 62 per cent of the total weight.

Anyone engaged in new product development should have a copy of the Standards readily available because it is essential to comply with them if the product is to be offered for sale under any of the above descriptive names. A copy can be obtained for five cents from the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C.

Examples of Formulations

White Bread and Rolls.—Satisfactory white bread can be made from flour, water, salt, and yeast (or a "sour dough"). Italian bread is usually based upon this simple combination of ingredients, and French or Vienna breads are scarcely more complicated. Such breads have a hard crust which is light in color, a coarse and tough crumb, and a flavor which is excellent when fresh but considerably less attractive when the bread is a day or so old. Table 61 gives example of formulations which have been suggested for these products. Formulas may vary greatly from one bakery to another and between different sections of the country.

TABLE 61

FORMULATIONS FOR FRENCH, ITALIAN AND VIENNA BREADS

	Italian	French	Vienna
	Parts	Parts	Parts
Flour	100	100	100
Water (variable)	60	60	60
Yeast (compressed)	1.75	1.75	1.75
Salt	1.75	1.5	1.75
Sugar	......	1.5	3
Shortening	......	2	3

Of course, the formulas shown in Table 61 can be, and usually are, modified by the addition of dough improvers, yeast foods, mold inhibitors, vitamins, minerals, and small quantities of enriching ingredients such as milk solids. The sponge and dough process is usually employed in

TABLE 62

COMPARATIVE FORMULAS FOR SOME WHITE PAN BREADS, ETC.

	Lean, Parts	Home Style, Parts	Premium, Parts	Egg, Parts	Army, Parts	Buns, Parts	School Lunch, Parts
Flour	100	100	100	100	100	100	100
Water (variable)	60	65	60	60	60	65	74
Salt	2	2.25	3	2	2.5	2.5	2
Sugar	3	3	10[1]	2.5	3	16	4
Milk (dry skim)	2	3	4	4	6	10	12
Shortening	3	9	......	.....	5	9	4
Malt syrup	1	......	......	2	2	1	0.5
Yeast (compressed)	2	3	1.75	2	2	4	1.75
Butter	...	......	8	3	.....	.....	......
Whole eggs	...	......	......	9	.....	.....	......

[1] Half honey and half invert sugar syrup.

making these breads. The flours used must have good amylase activity or the lack of fermentable sugar production must be compensated for by added diastatic malt. Strong flours are desirable, and long extraction flours or even some or all clear flours may be used.

The standard low-density soft-crust breads which comprise the greatest proportion of white bread sold in this country include much greater quantities of enriching ingredients than the lean breads described above. Table 62 gives formulas for several white breads varying principally in the amounts of enriching ingredients required.

Home-style, army, egg, and bun formulas are usually made up by the dough process while it is more common to make the others by the sponge and dough process. It is customary to use yeast foods, dough improvers, mold inhibitors, etc., according to the convictions of the formulator or the conditions imposed upon him as final product requirements.

Whole Wheat and Other Specialty Breads.—Breads designed to take advantage of demands for unusual flavors or for special nutritional

TABLE 63

FORMULAS FOR WHOLE WHEAT, RAISIN, AND CHEESE BREADS

	Whole Wheat, Parts	Cheese, Parts	Raisin, Parts
Flour	100[1]	100	100
Water (variable)	62	57	62
Salt	2	2	2
Sugar	3.5	2	2
Milk (dry skim)	2	2	4
Shortening	3	5	5
Malt syrup	0.5	...	...
Yeast (compressed)	3	3	3
Dehydrated cheddar	.....	10	...
Raisins	.....	...	50

[1] Must be 100 per cent whole wheat flour.

qualities can assume an almost unlimited range of forms and contents. In Table 63 are listed formulas for some of the more standardized varieties.

Several bread varieties of rather unusual composition which have been shown to have good commercial possibilities were recently described by Pickering (1956). A few of these formulas, adapted to the style used in this book, are given below to illustrate the possibilities.

Egg Twist Bread

100 lbs. bread flour (medium strength)
62 lbs. water (variable)
2.125 lbs. salt
0.5 lb. malt
0.375 lb. mineral yeast food
5 lbs. shortening
5 lbs. sugar
5 lbs. nonfat milk solids
5 lbs. egg yolks
2 lbs. compressed yeast

Vitality High Protein Bread

100 lbs. bread flour (high gluten type)
70 lbs. water (variable)
2.25 lbs. salt
2.125 lbs. yeast
0.25 lb. mineral yeast food
0.5 lb. malt
3 lbs. shortening
4 lbs. nonfat milk solids
6 lbs. soya flour
5.5 lbs. sugar
1.5 lb. wheat germ
0.5 lb. molasses

Old Fashioned Raisin Molasses Bread

65 lbs. bread flour (strong)
35 lbs. whole wheat flour
67 lbs. water (variable)
2.25 lbs. salt
2.25 lbs. yeast (compressed)
0.375 lb. mineral yeast food
4 lbs. shortening
3 lbs. molasses
3 lbs. brown sugar
3 lbs. nonfat milk solids
55 lbs. seedless raisins

Chuck Wagon Bread

100 lbs. bread flour (strong)
76 lbs. water (variable)
16 lbs. rolled oats
2.25 lbs. salt
2.25 lbs. yeast
0.25 lb. mineral yeast food
5 lbs. honey or dark corn syrup
1.5 lbs sugar
4 lbs. nonfat milk solids
4 lbs. shortening

Breads Requiring "Sours"

Rye Bread.—The most popular representative of this class is rye bread. It is true that rye bread of a sort can be made without using a sour dough, substituting in its place one of the special flavors distributed by bakery supply houses. These flavors consist usually of some organic acid plus caraway and other natural and artificial flavors. Most quality rye breads are prepared with commercially available dehydrated sours which contain viable micro-organisms of the type found in natural sour doughs. A formula using such a preparation is given below (Anon. 1947).

American Light Rye Bread

Sour dough	
Light rye flour	23 lbs. 6 oz.
Water	15 lbs. 3 oz.
Dehydrated rye sour	1 lb. 7 oz.
Dough	
Sour dough	40 lbs.
Light rye flour	6 lbs. 10 oz.
Clear flour	70 lbs.
Water (variable)	35 lbs.
Yeast (compressed)	2 lbs.
Malt syrup	5 lbs.
Salt	2 lbs. 4 oz.
Whole or ground caraway	8 oz.
Shortening	1 lb. 8 oz.

The sour dough comes out of the mixer at 80 F. and is fermented 22 to 26 hours. The dough comes out of the mixer at 76 F. and is given floor time of 1 to $1^1/_2$ hours.

There are many different types of rye bread. They differ from one another in the type of rye meal used, in the acidity of the crumb, and in the flavoring adjuncts such as spices which are included in the formula. The formula given above makes a relatively light (in color and in density) but flavorful loaf. At the opposite end of the spectrum are such items as Westphalian pumpernickel which has virtually no leavening action and contains 100 per cent whole rye in the form of slightly broken kernels. Westphalian pumpernickel is a very dense, dark, and chewy loaf.

Salt-rising Bread.—Salt-rising bread is an unusual specialty which owes its unusual texture and pungent aroma to a combined yeast and bacterial fermentation. It was formerly prepared by using a natural sour-dough method, but practically all of the product now being made in this country contains a commercial dry "yeast" preparation or culture. As is the case with many strong-flavored products, it exhibits a dichotomous distribution of acceptance, many people finding it extremely desirable while others dislike it. The odor is said to be reminiscent of cheese. Since cheeses can be found with a wide variety of flavors, most of which are due to bacterial action, this similarity is perhaps not unexpected.

The formula and procedure given below are attributable to Kohman (1955):

Salt-Rising Bread

Culture rehydration step		
Water	6 lbs.	
"Yeast" culture	1 lb.	
Nonfat dry milk		12 oz.
Sponge		
Water	15 lbs.	
Flour	20 lbs.	
Dough		
Water	15 lbs.	
Flour	40 lbs.	
Salt		10 oz.
Sugar	1 lb.	4 oz.
Shortening	1 lb.	4 oz.
Nonfat dry milk		10 oz. (optional)

The salt-rising culture or "yeast" is mixed with the milk powder. The mixture is added to boiling hot water and stirred well. The rehydrated culture is covered and kept warm (90° to 100°F.) for about nine hours. When gas begins to form, the preparation is stirred and allowed to stand until it is well aerated. It is then ready for the sponge. Do not allow the culture to ferment until it becomes sour and thin because it will lose much of its gas producing ability.

The sponge is prepared from one-half of the total water (110° to 130°F.) and one-third of the flour required for the desired number of loaves. The flour is added first, then the fermenting culture, and the whole is lightly mixed. The sponge is made warm, about 95° to 100°F., and kept at this temperature about two hours until it begins to drop. Care should be taken not to over age the sponge.

In making the dough, the remaining half of the water is heated to 120° to 160°F. and the shortening, salt, sugar, and milk powder are added. The dough flour is then added along with the sponge, and the mass mixed at slow speed just long enough to make a smooth dough. The dough should be warm (100°F.) and stiff enough to handle well by machine or hand. Scale it within 15 minutes and mold the dough pieces as soon as they come from the divider. Avoid chilling the dough at any time. Fill small pans half full of the dough and grease the tops of the dough pieces. Proof approximately one hour at 100° to 115°F. until the dough doubles its bulk and bake at the usual temperature.

Salt-rising bread is close-grained and firm so that the volume is only about three-fourths that of ordinary white bread. The loaves have a tendency to crack on the sides, so it is customary to mold the loaf in two parts or to pan as a double loaf so that the split comes in the middle.

It should be emphasized that this loaf cannot be made with ordinary bakers' yeast, either compressed or dry. The hot water reconstitution step would completely inactivate any preparation of *Saccharomyces cerevisiae.*

Potato Bread.—Potato bread can also be made using a primary ferment. Although a sour dough utilizing the action of wild yeasts on a potato mash was the former source of the typical flavor of potato bread, it is more common now to use a mixture of bakers' yeast, potato flour, and water. The following procedure has been suggested (Anon. 1952):

Primary ferment	
Yeast (compressed)	2 oz.
Potato flour	12 oz.
Water (85°F.)	3 lbs. 8 oz.
Dough	
Bread flour	12 lbs. 8 oz.
Water (cold)	5 lbs.
Yeast (compressed)	2 oz.
Sugar	8 oz.
Salt	5 oz.
Shortening	8 oz.
Malt extract	1 oz.
Nonfat dry milk	8 oz.

Combine the ingredients in the primary ferment and beat well. Allow to stand until it rises and breaks (about 30 minutes) then mix in the dough ingredients using enough water to make a dough of medium stiffness. The dough should come out of the mixer at about 80°F. Let the dough come to a full rise. Take it out to the bench in 20 minutes. Round and mould as usual. The above formula will yield 22 lbs.

SWEET DOUGHS

There are two major classifications of yeast-leavened sweet doughs. These are the remix sweet dough, which corresponds in a general way to a sponge dough product in the bread line, and the straight sweet dough. By varying the flavoring, filling, shape, and icing, an almost infinite number of kinds of cakes and rolls can be made by these two procedures.

Sweet doughs are much richer in shortening, milk, and sugar than are bread-type doughs, and in addition they usually contain whole eggs, egg yolks, or egg whites, or the corresponding dried products. Commonly used flavors include spices, vanilla, nuts and nut pastes, peels or oils of lemon or orange, raisins, candied fruits, etc.

A typical basic formula (Anon. 1953) is given below.

Straight Sweet Dough

Bread flour	80 parts
Cake flour	20
Sugar	20
Bakers' margarine	20
Whole eggs	20
Nonfat dry milk	5
Nondiastatic malt syrup	2
Salt	1
Yeast (compressed)	8
Water (variable)	42

The sugar, margarine (for which emulsified shortening may be substituted), salt, eggs, malt and milk are creamed together until homogenous and somewhat aerated. Then the flours are added slowly while mixing is continued. Finally, the water, in which the yeast has been dispersed, is mixed in and the dough developed. The dough should come out of the mixer at about 80°F. A fermentation period of about $1^3/_4$ hours is usually adequate.

To prepare a remix sweet dough, the above formula and procedure is followed in the initial stage. After fermentation, about 20 to 22 parts of a strong flour, 13 to 14 parts of sugar, 13 to 14 parts of butter, margarine, or emulsified shortening, and 13 to 14 parts of egg yolks (liquid) would be added to the dough. Mixing would be at a medium speed for the required length of time. No further fermentation is conducted, the dough is scaled as soon as it comes out of the mixer and made up after a short bench rest.

Some authorities suggest adding the eggs in a separate step after the creaming stage. Others add the flour before the water is added. Probably these changes do not alter the product character very much.

The basic formula given above is fairly rich although some increase in the enriching ingredients can be tolerated without destroying dough quality. The enriching ingredients can be reduced by at least half if a relatively lean dough is desired. As these ingredients are reduced, it is desirable to decrease the yeast also since the lowered osmotic pressure will tend to accelerate yeast activity. The absorption should be increased a few per cent as the dough is leaned down.

The function of the enriching ingredients is to soften the texture and make it flakier, improve the taste and color, and increase the nutritional quality of the product.

Dried egg products can be used in sweet yeast doughs. Although whole eggs are called for in the preceding formula, egg yolks can be substituted with little observable change in the quality of the product. Liquid skim milk or whole milk in equivalent quantities can be substituted for the nonfat dry milk. Any nondiastatic malt preparation can be used to replace the syrup. In place of the bread flour and cake flour mixture, flours milled specifically for a sweet dough operation can be substituted with advantages in economy and convenience. Of course, various dough improvers and yeast foods can be added to the formula with the usual equivocal results.

DANISH PASTRY

The distinguishing feature of Danish pastry preparation is the interleaving of dough sheets with layers of fat. In this respect the process is similar to that used with puff pastry. However, the only leavening action occurring in puff pastry results from the water vapor evolved in the oven while Danish pastry dough contains enough yeast to give a porous structure to the crumb. When properly made, these doughs will yield baked products that are flaky and short. The three-dimensional lattice of gluten fibrils is interrupted by layers of fat so that a pile of dough strata is formed in the finished food. The shortening itself is liquefied by the heat during the final stages of baking and absorbed into the dough so that it does not appear in the finished product as separate layers or particles.

Since it is important to maintain separation of the dough layers until the product goes into the oven, Danish pastry dough is rolled while cold. The usual procedure is to spread shortening over a fairly thick piece of dough, fold the piece over, sheet it out, fold it over again, sheet out, and repeat these operations until a many-layered structure has been developed. Refrigeration is desirable after each sheeting operation to dissipate the heat resulting from the mechanical action. Accumulation of this heat would result in eventual attainment of temperatures sufficiently high to melt the shortening and allow the dough layers to merge.

Danish doughs do not ordinarily receive much fermentation. An initial short period of 20 to 30 minutes in the refrigerator before the fat is rolled in allows some gas and flavor to be developed. Then the dough is usually refrigerated between each series of sheetings and in each of these cases some fermentation will occur. Proof time is short, usually 20 to 30 minutes, and this at temperatures below room temperature.

The following formula and procedure for making Danish pastry has been given by Wihlfahrt (1935).

Danish Pastry Procedure

Cream until light:		
Sugar		12 oz.
Malt		4 oz.
Butter	1 lb.	
Vanilla		1 oz.
Add to creamed mixture:		
Whole eggs	1 lb.	
Egg yolks		8 oz.
Mix together and add to above:		
Milk (cold)	4 lbs.	4 oz.
Yeast		10 oz.
Add while mixing:		
Hard wheat flour	5 lbs.	
Soft wheat flour	2 lbs.	
Blend together and roll in immediately after mixing:		
Butter	4 lbs.	
Pastry shortening	2 lbs.	

Wihlfahrt suggests rolling the above dough at three 45 minute intervals, making four folds each time and keeping the dough quite cold.

Special shortenings with a relatively high melting point are available for use in Danish pastries.

PROCEDURES—GENERAL

The Sponge and Dough Process

The sponge and dough method of mixing consists of two distinct stages, the first of which is called the sponge and the second the dough stage. The sponge usually contains from $^{1}/_{2}$ to $^{3}/_{4}$ of the flour, all of the yeast, yeast foods, and malt, together with enough water to make a stiff dough. Addition of all or part of the shortening may also be made at this stage although it is more common to add it later. One-half to three-fourths of the salt may be added to the sponge to control fermentation. The sponge is fermented until it begins to decline in volume, a phenomenon called "the drop" or "the break." The time required for this to occur is of course dependent upon too many variables (temperature, type of flour, amount of yeast, absorption, amount of malt, etc.) to permit any meaningful rule to be enunciated here. Frequently the variables are adjusted to give a drop in about 3 to 5 hours.

At the dough stage, the sponge is returned to the mixer and all of the remaining ingredients added. The dough is developed to a peak and then is returned to the fermentation room.

An extensive discussion of the techniques involved in judging adequacy of dough development would be out of place here. When tested by objective measuring techniques, optimum development is frequently taken to be the stage at which the dough mass exhibits maximum resistance to shear. Visually, the development is usually considered to be optimal when the dough mass exhibits a silky sheen and is thrown around the mixer bowl in one piece which stretches elastically from the mixer arm but does not break into pieces. When a piece of the dough is removed from the mixer and stretched with the fingers, a thin film can be formed which, when viewed by transmitted light, has a webbed appearance. Judging dough development with any degree of accuracy requires considerable skill which can be acquired only by experience. Frequently, mixing personnel achieve an ability to estimate the stage of development by the sound of the dough as it slaps the mixer bowl. This subject is discussed in somewhat more detail in the chapter on "Flour" and Swortfiguer (1950) gave a good discussion of the various stages in development.

The second type of mixing, called simply the "dough method," requires that all of the ingredients be incorporated during the first mixing step. According to Pyler (1952), the advantages of the sponge method are:

"(1) There is a saving of approximately 20 per cent in the amount of yeast used as compared with the amount required for a straight dough.

"(2) Bread produced by the sponge and dough method tends to have greater volume and a more desirable texture and grain.

"(3) The method possesses greater flexibility. Sponges can be held longer without marked deterioration of the final product, in contrast to straight doughs which must be taken up when ready."

Disadvantages of the sponge method result from the extra handling of the dough, the additional weighing and measuring, and the second mixing step. More labor, equipment, and power are required for the sponge and dough process.

Variations in the straight dough process which have been suggested to overcome some of its disadvantages include the remixed straight dough process in which the only ingredient added at the second mix is a small proportion of the water, and the no-punch method which involves extremely vigorous mixing. Continuous mixing processes can be considered either as straight dough methods or as sponge methods in which the "sponge" consists of the liquid ferment. From the standpoint of performance of the flour, it is more logical to consider them to be straight dough processes.

Calculating Dough Temperatures

The following empirical method has been suggested (Anon. 1950) for determining the temperature to which the ingredient water must be lowered (or the ice required) to yield the desired dough temperature.

Factors required to be known in order to make the calculations are: (1) desired dough temperature; (2) temperature of the flour; (3) temperature of the mixing room; and (4) machine allowance, which accounts for the heat accumulated during the mixing. The latter factor will vary with the type of mixer, the size of the dough, etc. It can be estimated by multiplying the exact temperature of a freshly mixed dough by three, and then subtracting from the product the sum of the exact temperaures of the flour, water, and mixing room.

Example:

Dough temperature = 80°F.
80 × 3 = 240
Flour temperature = 70°F.
Water temperature = 64°F.
Mixing room temperature = 78°F.
70 + 64 + 78 = 212
Machine allowance: 240 − 212 = 28

In order to determine the temperature of ingredient water which should be used in order to obtain the desired sponge or dough temperature, multiply the required temperature by three and subtract from this figure the sum of the exact temperatures of the flour and the mixing room, and the machine allowance.

Example:

Desired temperature = 80°F.
80 × 3 = 240

Machine allowance	= 28°
Flour temperature	= 70°
Mixing room temperature	= 78°
Total	176°

Necessary water temperature: 240° — 176° = 64°F.

In order to determine the amount of ice required to reduce the temperature of tap water to the desired temperature, subtract the desired temperature from the measured temperature of the tap water, multiply this difference by the total weight of water to be used in the dough batch, and divide the product by 144 (one pound of ice at 32° F. absorbs 144 B.t.u.'s). The resulting figure gives the number of pounds of ice required. Deduct this amount from the total pounds of water in order to determine the amount of tap water to be used with the ice.

Example:

Tap water temperature = 78°
Water required for the dough: 240 lbs. at 64°
$78° - 64° = 14°$
$14° \times 240$ lbs. $= 3360$
$3360 \div 144 = 23^1/_3$ lbs. of ice required
$240 - 23^1/_3 = 216^2/_3$ lbs. of tap water

CAUSES OF SOME DEFECTS IN BAKERY FOODS

In this section, an attempt will be made to summarize some of the fundamental causes of defects in bakery goods. Bread will be the principal example because it seems to be more sensitive to small changes in formulation or processing than other yeast-leavened foods. Most of the points brought out here are also applicable to sweet doughs and similar products.

Defects of Volume

These are caused, of course, by unusually large or unusually small quantities of gas being present in the dough piece at the time it becomes "fixed" by heat. Although gases other than carbon dioxide are present in the dough, and may even contribute substantially to the final volume of the product, their amounts are relatively inflexible as compared to carbon dioxide, and where the amount of gas is the proximate cause of the defect of volume, it is almost certainly the amount of carbon dioxide which is the variant from the norm.

The amount of gas evolved during the final critical period (proofing) may be relatively normal, with the defect in volume being caused by abnormal retention, either on the high or (usually) on the low side. If the retention of gas is too high or too low, it is possible that the characteristics of the flour have changed. Use of an excess of protease will decrease the ability of the vesicle walls to retain gases. Excess distention of the gas cells during proofing may cause some of them to rupture, with consequent loss of gas. Changes in the size or shape of the pan can cause actual as well as apparent changes in specific volume. In addition, there are apparent defects in specific volume (volume divided by weight) which are the result of improper scaling. The most scientific criterion for this characteristic is the specific volume, and such standards as the height, width, or sales manager's opinion are of little value.

If the volume of evolved gas is the cause of the fault, the abnormality will usually have had its origin in one of the following four things: (1) wrong proofing conditions—time, temperature, or both; (2) wrong amount or quality of yeast; (3) different diastatic activity than usual, or (4) variation in the amount of substances which accelerate or inhibit the fermentative activity of yeast (salt, phosphates, thiamin, etc.).

Defects of Crust Color

The color of the crust originates from the reactions of nitrogen-containing substances with reducing substances in the surface layers of the dough piece. The speed of these reactions is dependent upon the relative concentration of the reactants and the physical conditions under which they react. The two most important of the latter are probably the pH and the temperature. The rate of dehydration of the crust layers is very important to the speed of color formation. Dehydration to very low moisture contents concentrates the reactants to high levels and permits the temperature to rise above the boiling point of water. Under these conditions the rate of browning increases enormously. Thus it is possible for the crust to take on a dark color while the crumb does not noticeably change in hue. As a rule, browning reactions of the type we are considering take place much more rapidly under conditions of alkaline pH than they do under the moderately acid conditions found in the crumb. It may be that the reactions in crust are self-catalyzed, since nitrogen, probably in the form of ammonia, seems to be released by the reaction. This ammonia, though transient, could temporarily raise the pH to high levels in the crust layers.

The concentration of the nitrogenous reactants in doughs should remain relatively constant unless a considerable difference in flour specifications is encountered. More of the reactive end groups can be released for the reaction by adding fungal protease to the dough. Deficient reducing sugars may be due to imbalance of yeast activity and yeast substrate. The reducing sugars can be increased by using lactose, either as skim milk solids or dried whey. Since lactose is not fermented by yeast, it can be added in required amounts without much affecting gas production (some effect due to increased osmotic pressure may be noted at very high addition rates). Increasing top heat in the oven, or decreasing bottom heat, will tend to darken the crust. If the baking container shields any part of the dough from the radiant heat of the oven, a lessened crust color can be expected.

Defects of Taste and Aroma

Flour is a remarkably good adsorber of aromatic compounds. Paint, tobacco, solvents, and certain disinfectants are common odorous contaminants of flour. Contacts rarely occur in the mill under present conditions, but may occur during shipment or storage. Musty odors due to the use of inferior wheat or overlong storage of the flour are possible but rarely occur in practice. Any of these odors present in the flour will carry through in some degree to the finished baked goods.

Other ingredients in which off-flavors may occur are the shortening, especially butter, milk, and even the water. Any raw material procured from a reliable manufacturer can be expected to be of good flavor quality. Only in very unusual circumstances will this be found to be untrue. More likely sources of off-flavor are the means of transportation, storage areas, and equipment used in the bakery.

Deficient flavor is usually due to the use of insufficient salt or to inadequate fermentation. The remedy for the former is self-evident, and the latter can be corrected by increasing the time or the temperature of fermentation at any of the stages. Care should be used in accepting a diagnosis of deficient flavor, since it is rather clear that the great majority of consumers actually prefer a bread of bland flavor. Sour or acid flavor may be due to over fermentation and the corrective measures in this case are obvious.

Defects of Grain

Gross unevenness of grain, e.g., holes, streaks, and lumps, is due to inadequate sealing of the dough layers by the moulder or to excessive dusting flour or divider oil. Formation of an unusually thick and dry crust during intermediate proofing will also cause such defects.

Coarse grain can be caused by doughs which are too old or too slack, overproofing, pans which are too large or too small for the weight of the dough, or too low a temperature in the oven. Grain which is too close or tight can be caused by underproofing or overmixing. Out of balance formulations or weak flour can cause defects in grain. Some emulsifiers have been shown to cause relatively thick cell walls.

The crumb color is greatly affected by the grain. Small and uniform cell size are attributes contributing to whiteness of crumb, regardless of the background color of the cell walls. A dark or grayish cast may be due to use of long extraction flour with its higher content of bran pigments. The creamy or slight yellowish coloration which may or may not be desirable is due primarily to the fat soluble pigments of the wheat endosperm.

Defects of Symmetry

Defects in the shape of the loaf generally originate during molding or during placement of the dough in the pan. If the molder is compressing the dough cylinder too much, a loaf which is enlarged at the ends may result. If the compression is too slight, the loaf may be peaked in the center. Dough which is overproofed or made from weak flour may be the cause of misshapen loaves.

Defects of Break and Shred

Lack of shred may be due to: (1) excessive pan proofing; (2) excessive proof room humidity; (3) extremely young or extremely old dough; (4) too little steam in the oven, or (5) slack dough.

A very ragged break or shell tops may be caused by: (1) slightly young or slightly old dough; (2) crusting during pan proofing; (3) stiff dough; (4) excessive salt; (5) underproofing; (6) excessive top heat; (7) chilled doughs; (8) lack of salt; (9) hot flour or over aged flour; (10) over bromating; (11) too much dough in the pan; or (12) insufficient milk or shortening.

Defects of Texture

In this category it is desirable to consider not only the usual texture judgment arrived at by feeling the crumb with the fingers, but also the "mouth feel" or what some authors call "mastication." These characteristics are closely related. No doubt the mouth feel is the more sensitive of the two judgments.

Texture is partly a function of the grain size and uniformity and partly a function of the inherent elasticity and resistance to shear of the basic material. The adhesiveness of the crumb may also play a part. Doughiness or similar qualities should cause suspicion of excess absorption, wrong shortening or emulsifier, insufficient baking time or temperature, or excess fermentation. Crumbliness might be caused by insufficient absorption, very weak flour, excessive baking time or temperature or insufficient fermentation.

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CHAPTER 10

Samuel A. Matz

Formulating and Processing Chemically Leavened Goods

CHEMICAL LEAVENING AGENTS

Gas Sources

Carbon dioxide is the only gas currently used for aerating chemically leavened bakery products although oxygen derived from hydrogen peroxide has been patented as a leavening agent. The source of carbon dioxide is usually sodium bicarbonate, although ammonium carbonate and bicarbonate are sometimes used in cookies, and acetone dicarboxylic acid has been suggested and perhaps used experimentally. Both of these latter compounds decompose completely upon the application of heat and do not require added acids as does soda. Potassium bicarbonate has been employed as a component of leavening mixtures for baked products intended for sodium-free diets, but it is very hygroscopic and tends to impart a bitter flavor to the foods in which it is used.

The popularity of sodium bicarbonate as a gas source is based upon its low cost, lack of toxicity, ease of handling, tasteless end products, and high purity of the commercial product. An additional advantage is that its solutions tend to be less alkaline than, for example, the carbonates, so that localized areas of very high alkalinity are less apt to be formed as the granules dissolve in dough. It has some disadvantages also. Among them are its speed of solution at room temperature, a factor which reduces the amount of control over its action.

Specifications for soda should include a purity requirement, generally 99.9 per cent, and particle size requirements. The latter are determined by the use for which the soda is intended. A powdered sodium bicarbonate, 65 to 75 per cent of which will pass through a 200-mesh screen, is suitable for self-rising flour, pancake flour mixes, and other mixes which can be used soon after preparation. Granular soda must be used in mixes which have an expected shelf life of more than a few months. Particles which are too large may cause erratic bakeout and lead to brown or black spots on the crust. Common requirements for granular soda are that 100 per cent shall pass through an 80-mesh sieve and 75 per cent or less shall pass through a 200-mesh sieve. A complete particle size analysis of the two types of soda is given in Table 64.

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TABLE 64

PARTICLE SIZE DISTRIBUTION IN TWO TYPES OF SODA[1]

Sieving Distribution		Granular Soda Per cent	Fine Soda Per cent
Over Mesh Size	Through Mesh Size		
48	...	0	0
65	48	0.5	0.1
80	65	0.5	0.2
115	80	4.1	0.7
150	115	41.3	1.4
180	150	39.7	5.5
200	180	5.6	6.0
	200	8.3	86.1

[1] Adapted from Van Wazer and Arvan (1954).

When sodium bicarbonate is dissolved in water, a mixture of sodium ions, carbonate ions, bicarbonate ions, undissociated carbonic acid and dissolved carbon dioxide results. The proportions of the last four components are determined by the temperature of the water, the concentration of hydrogen ions (which is, of course, related to the amount of added soda), and the partial pressure of carbon dioxide over the solution. When other substances are added to the water, the situation becomes much more complex, and calculations of theoretical yields from doughs give values which differ by unpredictable amounts from the observed volumes. However, predictions of the direction of changes resulting from most variations can at least be made.

Considerable amounts of carbon dioxide can exist in solution above pH 8. Below the point of neutrality, very little of the compound exists in solution, and below pH 6 the amount present can be considered negligible for most purposes. In more complex systems, especially those involving colloidal components, much carbon dioxide (in one or the other of its forms) can exist in a "bound" state. Evidently the ions can be held by loose bonds to the electrophilic sites on proteins and other compounds. These bonds are evidently weak and are readily broken at higher temperatures or by competition for the carbon dioxide-containing ion by increased amounts of hydrogen ions.

Evolution of carbon dioxide from pure solutions of sodium bicarbonate is slow, especially near room temperature. When soda is added to dough, gas evolves at an appreciable rate, at least initially, because doughs usually have a pH of 5 to 6. In the absence of added acids, the dough pH quickly becomes alkaline and gas production decreases. To secure the maximum yield of gas, and to control the rate of evolution, acids are added to the dough along with the sodium bicarbonate. Soda crackers are a special case in which some of the neutralizing acid is obtained as the result of yeast activity.

Leavening Acids

The function of a leavening acid is to promote a controlled and nearly complete evolution of carbon dioxide from a dough in which the latter compound exists in its dissolved or bound forms. Obviously, the acid must be edible and yield edible and nearly tasteless end products, it should exist in the solid form at normal storage temperatures, it should be economical and easy to handle, and it should not have any bad effects on gluten. Several acids meeting these requirements and having the capacity to release gas from doughs at useful rates have been developed. Some of these are listed in Table 65. It should be emphasized that the amounts of acid required to give neutrality or any desired pH in a baked product may be quite different from the amounts calculated on the basis of the neutralizing value.

TABLE 65

SOME COMMON LEAVENING ACIDS

Chemical Name	Chemical Formula	Common Name or Abbreviation	Speed at Room Temperature	Neutralizing Value[1]
Monocalcium phosphate monohydrate	$CaH_4(PO_4)_2 \cdot H_2O$	$MCP \cdot H_2O$	Very fast	80
Monocalcium phosphate anhydrous	$CaH_4(PO_4)_2$	MCP	Slow	83
Dicalcium phosphate dihydrate	$CaHPO_4 \cdot 2H_2O$	DCP	None	33
Sodium acid pyrophosphate	$Na_2H_2P_2O_7$	SAPP	Slow to fast	72
Sodium aluminum sulfate	$Na_2SO_4 \cdot Al_2(SO_4)_3$	SAS	Slow	100
Sodium aluminum phosphate hydrate	?	$SAP \cdot H_2O$	Slow	100
Sodium aluminum phosphate anhydrous	?	SAP	Medium	110
Potassium acid tartrate	$KHC_4H_4O_6$	Cream of tartar	Medium fast	50
Glucono-delta-lactone	$C_6H_{10}O_6$	GDL	Slow	55

[1] Parts by weight of sodium bicarbonate which will be neutralized by 100 parts of the baking acid under standardized conditions. Neutralizing values may vary greatly as dough composition is changed.

The compounds listed in Table 65 are not "acids" in the usual chemical sense of the word. The phosphates and cream of tartar are actually metal salts of partly neutralized acids, while others such as sodium aluminum sulfate react with water to liberate acids. The initial pH of water solutions of these compounds is often in the range of pH 4 to pH 5, and this is only slightly below the level of some unleavened doughs. The chemical formulas of these compounds do not adequately define their function in doughs. Small amounts of additives included during manufacture can have a profound effect on the rate of reaction of the compound. Granule size and form also have important modifying actions. For example, companies specializing in leavening acids usually offer several types of sodium acid pyrophosphate. Although the chemical formulas of the main constituent are the same and analysis reveals variations only in the trace elements, the slowest reacting member of the series will promote an initial rate of gas evolution many times slower than the rate given by the fastest reacting member.

According to Tucker (1959) there is some evidence that the activity of enzymes in flour can change the reactivity of sodium acid pyrophosphate, particularly the slow-reacting type. He has evaluated certain flours which speeded up the reaction of slow-type sodium acid pyrophosphate to three or four times the normal rate. Freshly milled flours from new-crop wheat were particularly potent in this respect.

Baking Powder

According to the definition issued by the federal government, "baking powder is the leavening agent produced by the mixing of an acid reacting material and sodium bicarbonate, with or without starch or flour; it yields not less than twelve per cent of available carbon dioxide. The acid reacting materials in baking powders are: (1) tartaric acid or its acid salts; (2) acid salts of phosphoric acid; (3) compounds of aluminum; or (4) any combination in substantial proportions of the foregoing."

TABLE 66

TYPICAL BAKING POWDER FORMULAS[1]

	Household Types				Bakers' Types		
Component	A	B Lbs.	C	D	A	B Lbs.	C
Soda (semi-granular or granular)	27	30	30	30	30	30	30
Monocalcium phosphate	..	38	12	12	5	..	12
Sodium aluminum sulfate	..	..	23	23	..	..	23
Sodium acid pyrophosphate	..	..	..	..	36	42	
Cream of tartar	47	..	..	..	..		
Calcium lactate	..	..	..	..	2	..	..
Corn starch	24	32	35	28	27	28	28
Calcium carbonate	..	..	..	7	..	..	7

[1] Adapted from (Anon. 1953).

The requirement for twelve per cent of available carbon dioxide could theoretically be satisfied by including about 23 per cent sodium bicarbonate. However, the necessity for a margin of safety to compensate for loss of gas in storage and other conditions operating to reduce yield in any given sample dictates the use of a greater amount. Most manufacturers have formulas calling for about 26 to 30 per cent of soda. The remainder of the baking powder consists of leavening acids, fillers and diluents such as the starch and flour mentioned in the above definition, and compounds such as calcium lactate or hydrated calcium silicate (Miller 1960) which have a modifying effect on the evolution of carbon dioxide from the system. There is ample evidence that the diluents are not entirely inert, but serve to inhibit premature reaction of the leavening components due to moisture pick-up during storage and to modify to some extent the reaction rates during the first stages of mixing.

Table 66 gives suggested compositions for some typical baking powders. The compounding of leavening mixtures such as these requires a high degree of skill and experience. Except in very large baking plants, it will probably be found desirable to purchase prepared baking powders.

FORMULATION AND PROCESSING OF CHEMICALLY LEAVENED GOODS

Function of the Ingredients

The gluten proteins of the flour serve as the basic structural element in chemically leavened foods, just as they do in bread. However, the use of relatively smaller amounts of flour, the weaker (less extensible) protein in the soft wheat flours which are customarily employed, and the lower amount of protein in the flour, result in a softer, crumblier texture in cakes and similar products. In most chemically leavened foods, the protein of the flour is inadequate in quantity and quality to support an expansion of the extent found in bread so that they are of higher density than the latter product. Table 67 lists some specifications for soft wheat flours intended for use in particular types of chemically leavened foods.

In addition to their obvious function as sweeteners, sugars have a ten-

Table 67

COMPOSITION AND USES OF SOFT WHEAT FLOURS[1]

Bakery Products in Which the Flour is Used	Bleached?	Protein, Per cent	Ash, Per cent
Angel Food cakes	Yes	7.5 to 8.0	0.32 to 0.35
High ratio cakes and cookies (no spread)	Yes	7.5 to 8.0	0.32 to 0.35
High ratio spread cookies	No	7.5 to 8.0	0.32 to 0.35
Layer cakes and pound cakes	Yes	8.0 to 8.5	0.35 to 0.38
Slightly rich wire-cut cookies (no spread)	Yes	8.0 to 8.5	0.35 to 0.38
Cracker topping	No	8.0 to 8.5	0.35 to 0.38
General line of cookies	No	9.0 to 9.5	0.39 to 0.42
Cracker dough	No	9.0 to 9.5	0.39 to 0.42
Sugar cones	No	9.0 to 9.5	0.39 to 0.42
Doughnuts	No	9.0 to 9.5	0.39 to 0.42
No spread ice box cookies	Yes	9.0 to 9.5	0.39 to 0.42
Loaf cakes	Yes	9.0 to 9.5	0.39 to 0.42
Low ratio cup cakes	Yes	9.0 to 9.5	0.39 to 0.42
Lunch box cake items	Yes	9.0 to 9.5	0.39 to 0.42

[1] Adapted from Harrel (1959).

derizing effect on the crumb and promote the coloring of the crust. Sucrose is less effective in coloring the crust than are invert sugar and glucose. The situation is thus different than in yeast-containing doughs where the invertase of the yeast rapidly converts sucrose to glucose and fructose. No such action is observed in cakes and cookies, and the sucrose remains intact and non-reducing throughout the oven stage. Sugars retain moisture in the crumb and thereby retard staling. Once again, glucose or invert sugar are more effective on a weight for weight basis than sucrose because of their lower molecular weight and consequently greater osmotic effect. As the concentration of sugars is increased, the batter has a tendency to become more fluid. Less air is entrained under these conditions, but the batter can be conveyed more easily.

An important function of the shortening component of batters is to entrap air during mixing. Not only do these air bubbles contribute directly to the leavening effect, but they also help to control grain size by serving as foci for gas evolution. Microphotographs of batters have shown that all of the air bubbles are enclosed in layers of fat. These observations demonstrate unequivocally the importance of the creaming function of shortening, regardless of whether or not the fat is creamed in a separate stage. Shortening also tenderizes the crumb and may contribute slightly to the flavor of the product. Emulsified shortenings increase the amount of water which can be used and thus contribute to the tenderness and resistance to staling of the finished product.

As mentioned before, the gluten of flours used in cakes has characteristics not conducive to the formation of large cells or thin cell walls. These deficiencies are remedied to some extent by using egg whites in the formula. Proteins of the egg form the vesicle wall in combination with gluten and permit the entrapment of air during mixing. In angel food cake the entire leavening effect is obtained from the air enclosed by the egg white during vigorous whipping. Egg white proteins themselves do not have sufficient mechanical strength, when in thin films, to withstand oven expansion or handling after baking and do not contribute the texture expected in cakes. These attributes must be obtained from flour. Eggs also contribute flavor, which may or may not be desirable, and are important sources of color. Egg yolks contribute emulsifying and tenderizing effects. Eggs are frequently the only material that can be used to compensate for an excessively weak flour.

Milk accentuates crust color as a result of its content of lactose, a reducing sugar. Skim milk appears to exert a toughening effect on the crumb, but with whole milk this effect is balanced by the lubricating or tenderizing action of the milk fat. The flavor contributed by milk is generally considered desirable, and the sugar it contains helps retard staling.

General Rules for Formulating Cakes

There exist more or less traditional rules for assuring "formula balance" or the correct proportioning of ingredients. These will be summarized here, but it should be understood that slavish adherence to their limitations is not necessary. They have worked well in practice in the past, but the development of new ingredients and new processing methods may very well allow the "rules" to be disregarded in some cases.

On a flour weight basis, sugar should be 110 to 160 per cent in yellow layers, 110 to 160 in white layers, and 110 to 180 per cent in devils food and chocolate layers. Eggs as liquid eggs should be equal or exceed the shortening. Total liquid including the water in the eggs and milk should exceed the amount of sugar by approximately 25 to 35 per cent. Shortening should fall in the range of 30 to 70 per cent. Sodium bicarbonate should be 1.2 to 2 per cent and salt from 3 to 4 per cent of the flour.

If the amount of sugar in a formula is increased, the egg content should be increased an equal amount. More shortening should be added when the percentage of eggs is increased. Additional water is usually not added when the formula contains dry milk, but if the formula water is not sufficient to equal the reconstitution water for the milk, add about one per cent of water for each additional per cent of milk solids.

The following differences are usually found: Rich formulas need less chemical leavening because they incorporate more air during mixing, the batters display lower specific gravity for the same reason, and they perform better at a lower baking temperature. Batters baked in large piece sizes require less water and less leavener than those baked in small piece sizes.

Examples of Cake Formulas

Most authors consider the yellow layer cake as the basic type, but it is probably more logical to allocate this spot to the white layer cake since the yolk solids—the additional ingredient in yellow cakes—do not contribute any essential property to the cake or batter.

A formula for very lean white cake made in our American military installations for troop feeding (Anon. 1950) is shown on the next page. Although this recipe is important as an approximate lower limit of "richness," cakes including considerably more enriching ingredients are desirable from a taste and texture standpoint. An example of a formula for a rich white layer cake which is considered basic from our point of view is also given. It is essential to use high emulsifying shortening in cakes which have a high proportion of sugar to flour, the so-called "high ratio" cakes. Of course, flavoring materials must be added to the basic formulas.

In the case of white layer cakes, the flavor is nearly always vanilla. About one-half of one per cent of single strength vanilla extract or artificial vanilla is a common level of addition.

WHITE LAYER CAKE

	Per cent
Flour	25.6
Sugar	25.6
Shortening, hydrogenated	11.2
Egg whites	16.0
Evaporated milk	10.2
Baking powder	1.6
Salt	0.6
Water	9.2

RICH WHITE LAYER CAKE

	Per cent
Sugar	29.5
Flour	21.0
Shortening, emulsified	11.5
Egg whites	16.0
Milk, whole	20.0
Baking powder	1.3
Salt	0.7

The author developed for the Armed Forces a "universal" cake mix which is very versatile as a result of its resistance to failure even when rather high levels of flavoring ingredients are added. It also performs fairly well even when considerable deviations from the recommended mixing procedure occur. The formula is given here as an example of a basic white layer cake prepared from all dry ingredients.

UNIVERSAL CAKE MIX

	Per cent
Flour, 6 per cent moisture	37.51
Sugar	41.00
Shortening, high stability with added emulsifiers	13.70
Dried egg whites	3.00
Nonfat milk solids	2.50
Sodium bicarbonate	0.54
Sodium acid pyrophosphate	0.15
Monocalcium monohydrate	0.55
Salt	0.90
Powdered vanilla	0.15

About 35 to 40 per cent water will be added to the above dry mix, the exact amount depending to some extent on the quality of the flour and the efficiency of the emulsifier.

The principle difference between yellow layers and white layers is that the former contain whole eggs instead of egg whites. In other words, the "additive" to our basic mix is egg yolks. A possible formula would be the rich white layer cake recipe given above to which 12 to 13 per cent whole eggs are substituted for the egg whites and about 2 to 3 per cent additional milk is included to supply necessary moisture. Rumsey (1959) gives a formula range which will include most satisfactory recipes. Below is a slightly modified version of his formula.

FORMULA RANGE FOR YELLOW LAYER CAKES

	Per cent
Flour	21 to 23
Salt	0.5 to 0.75
Shortening	8 to 12
Skim milk solids	2 to 3
Baking powder	1 to 1.5
Whole eggs	10 to 14
Water	22 to 25
Sugar	24 to 32

The recipe which follows was developed to take full advantage of the special properties of whole eggs.

TYPICAL YELLOW LAYER CAKE

	Per cent
Flour	21.5
Sugar	30
Shortening, emulsifier added	11.5
Whole eggs	12.5
Whole milk	22.4
Baking powder	1.3
Salt	0.8

Yellow cakes are particularly adaptable to the addition of special flavors. Spice cakes are essentially yellow layer cakes to which, for example, mixtures of cinnamon, nutmeg, ginger, and allspice in the ratio of 8:6:1:1 are added. Pumpkin, applesauce, and mashed bananas may be added to spice cakes to furnish additional varieties. The above formula will support moderate additions of these adjuncts without failing. Larger quantities may necessitate increases in the flour and eggs.

Gingerbreads may deviate considerably in taste, texture, and appearance from yellow cakes, but they are usually formulated in accordance with much the same rules. The basic flavors in gingerbread are molasses and spices, and a coarser texture is acceptable and usually desired.

TYPICAL GINGERBREAD FORMULA

	Per cent
Cake flour	21.1
Sugar	8.4
Molasses	33.5
Shortening	9.4
Nonfat milk solids	2.1
Whole eggs	8.4
Salt	0.5
Sodium bicarbonate	0.2
Baking powder	0.5
Cinnamon	0.5
Ginger	0.5
Allspice	0.2
Water	14.7

A small amount of soda in addition to that contained in the baking powder is included in the above formula in order to neutralize the natural acidity of the molasses.

Cakes containing cocoa (or chocolate liquor) can be divided into two classes, devils food cakes and chocolate cakes. The difference is principally one of pH although texture, color, and flavor are affected by the changes. Chocolate cakes may be considered as a basic cake to which cocoa or chocolate liquor has been added, and their pH is close to that of a yellow cake. Devil's-food cakes are made with extra soda and have a crumb pH which is definitely alkaline. The next two formulas will illustrate the differences in preparation.

CHOCOLATE CAKE

	Per cent
Flour	18
Sugar	27.5
Shortening	10.6
Nonfat dry milk	2.5
Chocolate liquor	3.5
Baking powder	1.0
Salt	0.8
Whole eggs	15.0
Water	21.2

Cocoa takes up a considerable amount of water when added to a batter. This effect should be compensated by the addition of moisture to the base formula. As a rough rule of thumb, add water equivalent to 75 to 100 per cent of the weight of the cocoa. Most authorities recommend reduction of the shortening by an amount equal to the cocoa butter contained in the cocoa or chocolate liquor. It is doubtful that this change is imperative in any but the most delicately balanced formulas. If it is desired to account for the cocoa butter in this manner, consider the chocolate liquor to contain 50 per cent fat which has a shortening value one-half that of hydrogenated vegetable oils. Thus, addition of ten per cent chocolate liquor would call for a reduction of two and one-half per cent in the shortening.

DEVIL'S-FOOD CAKE

	Per cent
Flour	17.3
Sugar	26.8
Shortening	9.6
Nonfat dry milk	3.8
Whole eggs	9.7
Egg whites	2.9
Water	24.1
Cocoa	3.8
Salt	0.8
Baking powder	0.7
Sodium bicarbonate	0.5

Foam type cakes, such as angel food, are properly included in the chapter on air-leavened bakery goods since they do not contain chemical leavening agents, at least in the original form. However, chiffon cakes, which derive a considerable portion of their leavening from an egg white foam, can be discussed here since they require chemical leavening agents to attain the required volume.

CHIFFON CAKE

	Per cent
Flour	20.0
Sugar	26.5
Vegetable oil	9.5
Egg yolks	16.0
Baking powder	1.0
Salt	0.5
Water	6.9
Egg whites	19.5
Cream of tartar	0.1

The above formula indicates a separation of egg yolks and egg whites. In the usual batch mixing process, the egg whites and part of the sugar are beaten to a stiff foam and then the remainder of the ingredients are folded in. It is possible to mix and aerate the complete batter at one stage with some of the new continuous mixers. Flavors which can be added to chiffon cakes include vanilla, almond, and citrus flavors, particularly the latter.

Principles of Processing Chemically-Leavened Goods

There are perhaps five major categories of mixing methods for batters although, admittedly, what constitutes a minor modification is very much a matter of opinion. The five categories discussed here are: (1) single stage mixing; (2) two stage mixing, (3) creaming methods, (4) blending, or flour batter, method, and (5) sugar-and-water method.

The single stage mixing process is the simplest of them all and consists of dumping all of the ingredients into the mixer bowl and beating them with the wire whip or batter beater until they are homogenous. Usually, the batter is beaten at low speed for 1 to 3 minutes, or until the dry ingredients have been wetted, and then the mixer is turned to high speed or second speed for 5 to 8 minutes. Variations of this method include adding the leaveners near the end of the mixing period, or adding the eggs near the end with a total mixing time much reduced from the normal. The obvious advantage of this process is the saving of time which results. Disadvantages are said to be poorer grain, texture, and volume in the finished product.

Two-stage batters are mixed by placing all of the dry ingredients and part of the liquid materials into the bowl and mixing until a homogenous or creamed mass results. The remainder of the liquid is then added, usually gradually, and the mixing completed. Variations in this method usually involve changes in the stage at which the eggs are added.

The creaming process requires that the sugar and shortening be beaten until a light and fluffy ("creamed") mass is obtained. The eggs are then added while creaming is continued at medium speed, and finally the milk and flour are added alternately, in small portions. This method allows entrapment of a maximum number of small air bubbles in the fat with a consequent good effect on the grain in the finished product. It also does not develop the flour gluten as much as some of the other methods and this improves the texture of the cake somewhat.

The blending method requires the placing of flour and shortening in the mixing bowl and blending them together until the flour particles are thoroughly coated by the fat. The remainder of the dry ingredients is then added and the batter mixed until it is homogenous. Finally, the remaining liquid is added in portions and the mixing continued for a predetermined period. A modification which is frequently used requires that the sugar and eggs be beaten together to form a foam before they are added to the flour and shortening mixture. The chief advantage of the blending method is that it permits a very thorough dispersion of the shortening throughout the batter. This results in a very fine and uniform grain. On the other hand, the blending method does require more time and the use of more equipment than, for example, the single-stage method. Pyler (1952) also says that cakes made by this method are tougher and have lower volume.

In the sugar-water method, all of the sugar and one-half of its weight in water are placed in the mixing bowl and beaten for 30 seconds at medium speed in the first stage. Next, the shortening, flour, dry milk, salt and baking powder are added and the bowl contents beaten at medium speed for about five minutes. The leaveners must be reduced by one-fourth and superglycerinated shortening used for best results by this method. Advantages secured by this procedure are better crust color, tenderer crust, and improved volume as compared to cakes prepared by other methods.

As a general rule, layer cakes are baked at oven temperatures of 360° to 400°F. Cooler ovens tend to give cakes which are flat on top and exhibit excess shrinkage around the circumference. The cakes may also be too tender. Higher temperatures result in peaked cakes with cracked centers. In addition, more holes and tunnels develop in the crumb and the products may be tough and low in volume.

Cake Faults and Their Remedies

Material in this section is attributable principally to Wihlfahrt (1953) and in part to Thelen (1951).

(1) **Volume Too Low.**—Can be caused by the use of insufficient amounts of leavening agents, in which case the remedy is obvious. If batters are allowed to stand too long at too high temperatures, an initially adequate leavening action may be lost as a result of premature reaction of the bicarbonate and the leavening acids. This can be true even when delayed action leaveners are used. Undermixing can cause low volume because of reduced aeration of the batter. An excessively high oven temperature can set the structure of the cake before the full effect of the leavening gases has been exerted. Improper balance of ingredients, or improper types of ingredients, especially the flour or shortening, can reduce the expected volume markedly.

(2) **Defects of Texture.**—Gumminess, doughiness, or chewiness are often the result of underbaking or improper cooling before packaging. Such faults are readily corrected by increasing the baking time slightly or by thorough cooling before wrapping. If these faults are due to improper formulation, the exact cause may be harder to spot although the percentage of water and the type and quantity of shortening should be checked first.

Toughness may be due to use of too strong a flour, overbaking, inadequate amounts of water, overmixing with consequent overdevelopment of the gluten, not enough sugar, inadequate amounts or wrong type of shortening, or underscaling.

(3) **Defects of Crust Appearance.**—Spotted crusts can be due either to a non-homogenous batter or to bubbles in the crust. The former problem can be corrected by using a difference sequence of mixing, longer mixing, or more severe mixing conditions. The latter difficulty may be the result of unsuitable types of leaveners, batters which are too viscous, or excessive oven heat.

Bursting of the crust may also be due to high baking temperatures, or to overmixing, too much flour or flour which is too strong.

Pale crust color can result from a baking temperature which is too low. The oven as a whole may be set at too low a temperature or the heat distribution may be faulty with inadequate radiant heat reaching the crust. Conversely, crust colors which are too dark may result from undesirably high oven temperatures. In addition, pale crust colors can result from underscaling with resultant shielding of the top crust from radiant heat by the pan sides. Too much sugar, and particularly too much reducing sugars such as are found in corn syrups or in honey, can cause darkening of the crust even though baking conditions are correct as judged by the condition of the interior of the cake.

(4) **Coarse or Irregular Grain.**—Tunnels and large holes at the bottom of the cake may result from excessive bottom heat during baking. Too cold an oven can cause the grain to be open. Wet streaks are often due to underbaking. Undissolved spots of material in the crumb are not always the result of undermixing, although this is probably the usual cause. Some ingredients, particularly milk solids, will form agglomerates which are virtually indestructible by the usual mixing procedures if they are improperly stored. Both undermixing and overmixing can create a coarse, open grain in the finished product. An excessively close or fine grain is more often due to overmixing.

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CHAPTER 11

C. G. Harrel

Air Leavened Bakery Products

The contents of this chapter include discussions of processing procedures and formulations not only for foods which are leavened solely by entrapped air, such as angel food cake, but also for products leavened by other gases, such as injected carbon dioxide.

Presumably, the development of air-leavening techniques for bakery foods followed by some thousands of years the invention of yeast leavening, but it certainly antedated the use of chemical leaveners. Although air leavening might seem at first glance to be a simpler process than yeast leavening, the necessary refinement of ingredients, formulas, and processing techniques required for the satisfactory production of sponge cakes and the like did not occur until fairly recent times. Yeast leavening of cereal foods is found, along with the allied art of brewing, in fairly primitive cultures, but appreciation of, and demand for, air-leavened bakery products suggests a rather sophisticated cuisine and selective palates.

Air leavening of baked foods requires a vigorous mixing step (or mixing under pressure) during which bubbles of gas are incorporated by films of extensible colloidal material. Egg albumen in the form of egg whites was probably the first foam-producing agent used in the preparation of air-leavened baked products. This material has many excellent properties. It is very extensible, permitting a voluminous foam to be prepared from relatively small amounts of egg white; its foams are strong enough to support themselves and other ingredients in large masses; it coagulates or heat denatures within a range of time and temperature readily attained during baking; and the coagulated films have properties which contribute to desirable appearance and eating quality in the finished cake. In addition egg whites are edible, nutritious, and relatively tasteless. Disadvantages of egg whites include the exceptional sensitivity of their foams to small amounts of lipids, their cost, and the slight taste and odor which they contribute to the product.

Air-leavened doughs can also be made without eggs. "Beaten biscuits" are an example of foods prepared in this manner. Gluten, however, is not a very good whipping agent. Since it can be made into foams of very low density by using internal gas formers such as yeast or baking powder,

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its deficiencies for air-leavening purposes must lie in its inability to inclose or to retain a sufficient volume of air during mixing. Beaten biscuits require a great expenditure of energy in order to obtain a very small amount of leavening action. Below are given a representative modern formula and a procedure for making beaten biscuits.

BEATEN BISCUITS

Formula

100 parts flour
3 parts sugar
2 parts salt
20 parts shortening
35 parts milk

Procedure

Cream the dry ingredients and the shortening together, then blend in the milk. A very stiff dough will result. This is beaten continuously, with folding, for about thirty minutes by hand, or it can be run through a special "biscuit machine" which is made especially for this purpose. The beating and folding incorporate and subdivide bubbles of air. As the process is continued, bubbles or blisters will be seen just below the surface of the dough. If the biscuit machine is used, the dough will begin to crack or pop as it is pressed between the rollers when the final stage is approached.

The dough is rolled out into a one-half inch sheet, cut into circles, and docked with the tines of a fork or with a special instrument.

Baking is conducted at 350°F. for about 30 minutes. The final product is very pale in color, quite dense, and has an unusual and coarse texture.

Rotheram (1901) gave an early version of the above recipe. He called the product "Wafer Biscuits."

Wafer Biscuits

$^{1}/_{2}$ lb. flour
2 oz. butter
$^{1}/_{2}$ tsp. salt
Milk

"Rub the butter very thoroughly into the flour; add the salt and mix into a stiffish paste with milk; work smooth and put the paste on a floured board; beat it all over for quite ten minutes to make the biscuits full of bubbles; roll out as thin as possible on a floured board with as little flour as necessary. Cut in large squares, bake in a quick oven to a very pale color."

Barackman (1959) has quoted some recipes from Webster (1878) which illustrate how air-leavening was used in some French baked goods about the middle of the nineteenth century. The simplest product was probably the sponge cake.

Sponge Cake

"Ten eggs, their weight of fine sugar, the weight of six eggs of flour. Blend together with a whisk and beat for one-half hour. Bake in a lined and covered pan for one and one-half hour."

A somewhat later cookbook quoted by Barackman (1959), that of Kellogg (1892), gave the following recipe for sponge cake:

6 eggs, use whites only
1 cup sugar
Lemon juice
$^2/_3$ cup flour

"Sift flour 3 or 4 times, add a pinch of salt to egg whites and beat until stiff. Add lemon juice and beat until very stiff. Add flavoring and sugar. Fold the flour in lightly and quickly. Bake slowly for 35 to 50 minutes."

Addition of lemon juice in this latter recipe may represent an intuitive recognition of the value of acidifying albumen foams.

INCORPORATION OF AIR INTO BATTERS AND DOUGHS

Lowe (1955) has discussed the use of air as a leavening agent in baked foods. The following comments are pertinent:

"**Air.**—Air may be incorporated into a batter through an egg-white foam, by creamed fat and sugar, and to a lesser extent by aerating the flour through sifting and by beating the batter. If a batter contains 100 ml. of air, the air will increase to about 137 ml. when heated from 32° to 212°F. Such batters often more than double their volume in baking. Thus it is obvious that gas must be generated in the batter in addition to occluded gas to obtain this expansion."

Air plays a role in leavening beyond its expansion in the baked product. Dunn and White (1939) found that pound cake from which the air is evacuated does not increase in volume during baking. Yet, if the air is not evacuated, half of the expansion during baking is attributed to steam. They conclude that the water evaporates into the small air cells; then expansion of this water vapor and the air occurs. Hood and Lowe (1948) also find that if the air is completely evacuated there is no volume increase during baking of air-steam leavened cakes.

Steam.—One volume of water forms about 1600 volumes of water vapor, so that steam has great leavening ability, even in products containing as little water as pastry. Angel cake contains a large quantity of air, yet Barmore (1936) has calculated that steam brings about 2 to 3 times the expansion in baking angel cake as the incorporated air.

The effectiveness of steam as a leavening agent in cake varied with the type of fat used and whether carbon dioxide from baking powder was present. Thus steam is a major leavening in air-stream leavened cakes, but is less important in the air-steam-carbon dioxide leavened cakes. The relative increase in volume of cakes from the different leavening agents follows:

Leavening	Type of Fat in Cake		
	Butter, Per cent	Oil, Per cent	Hydrogenated lard, Per cent
Air-steam leavened cakes			
Increase from air	19.8	11.4	25.0
Increase from steam	80.2	88.6	75.0
Air-steam-carbon dioxide leavened cakes			
Increase from air	8.0	5.6	6.7
Increase from steam	32.3	44.1	20.7
Increase from carbon dioxide	59.7	50.3	73.1

It is quite evident that air plays an important part in the leavening of all types of cakes. Steam likewise plays a very significant part. If air is stated to be responsible for the leavening of angel food cakes, sponge cakes, pound cakes, chiffon cakes, etc., you will be led astray. The part that air plays in conjunction with other gases, such as steam, carbon dioxide, nitrogen, or many others that might be used, will be indicated.

There are six methods of incorporating air into bakery products. These are as follows:

(1) The recent development of highly emulsified shortening, such as lactylated shortening, an example of which is Durkee's 67, patented by Iveson *et al.* (1954).

(2) Whipping eggs and sugar plus certain additives that may or may not be added.

(3) Creaming shortening and sugar.

(4) Mixing under pressure.

(5) One hundred per cent air leavened bakery products.

(6) Aerated flour.

Each of these methods will now be considered in detail.

Highly Emulsified Shortenings

The most powerful emulsifying air entrapping shortenings are the lactylated types.

The specially prepared shortenings designed to entrap and hold air during the creaming process probably date back to 1890, with gradual improvement up to the present date.

Haines (1959) participated in the adaptation of lactylated shortening, with its air-entrapment qualities, to use in cake mixes which were partially leavened by chemical means. He stated, "The incorporation of larger amounts of air in the batter by the use of a powerful emulsifier necessitates a reduction in the soda level to avoid overleavening by a combination of air expansion in the oven and carbon dioxide generation and expansion. The reduction in soda would be generally proportional to the reduction in batter specific gravity. A soda level of 0.5 per cent for white layer cake mixes has been found to be a satisfactory combination with batter specific gravities of about 0.65."

Whipping of Egg Solids (Whites, Yolks, or Whole Eggs) with Sugar to Incorporate Air

Angel food, sponge, pound and chiffon cakes are a few examples of this method for incorporating air.

The following formula together with the suggested method of preparation is given for the production of angel food cake.

Angel Food Cake

Ingredient	Lbs.	Oz.	Percentage	Method
Egg whites	2	2	42.2	Whip to a wet peak
Sugar	1	0	19.96	
Salt		1/2	0.59	
Cream of tartar		1/2	0.59	
Sugar	1	2	22.30	Fold in very slowly
High grade angel food cake flour		12	14.36	
Total	6	4	100.00	

Scale 10 inches deep pans—1 lb. 7 oz.
Bake at 375°F. to 400°F.

Frequently angel food cake formulas contain very small percentages of leavening ingredients to further increase the volume. The egg whites for this type of cake for prepared mixes are usually specifically prepared to increase the whipping qualities. These dried egg solids may contain one of the following additives:

Sodium desoxycholate—Kline and Singleton (1959)
Triethyl citrate—Kothe (1953)
Triacetin—The Pillsbury Company, patent pending
Sodium oleate
Oleic acid

The first two of these additives are covered by patents.

The causes of failure in angel food cake and their suggested remedies are given on the next page.

Angel food cakes are very sensitive to certain types of fats. Mineral oil and cholesterol do not have any appreciable effect on the volume of the angel food. All of the oils containing glycerides have a very marked effect on the volume. The greater the unsaturated fats present, the more the volume is decreased. The following experiment illustrates this effect. A plastic bowl was used in making a French salad dressing. This bowl was

CAUSES OF FAILURE

Defect	Cause	Remedy
Undersized cake	(1) Overbeating or underbeating egg whites	(1) Beat egg whites, sugar, salt, and cream of tartar to a wet peak
	(2) Overmixing after flour is added	(2) Fold in just enough to incorporate
	(3) Sugar content too high	(3) Balance formula
	(4) Oven too hot	(4) Regulate temperature
	(5) Cakes removed from pan too soon after baking	(5) Allow cakes to cool before removing from tins
	(6) Cakes underbaked	(6) Bake thoroughly
	(7) Greased pans or tins	(7) Do not grease tins for angel food cakes
Dark crust color	(1) Oven too hot	(1) Regulate temperature
	(2) Cakes overbaked	(2) Give proper bake
	(3) Excessive sugar content, causing cake to have sugary crust	(3) Balance formula
Light crust color	(1) Cakes underbaked	(1) Bake correctly
	(2) Cool oven	(2) Regulate temperature
	(3) Overbeaten or overmixed batter	(3) Mix properly
Tough crust	(1) Oven too hot	(1) Regulate oven temperature
	(2) Sugar content too high	(2) Balance formula
	(3) Improper mixing	(3) Exercise care in assembling batter
Thick and hard crust	(1) Overbaking	(1) Lessen baking time
	(2) Cold oven	(2) Regulate temperature
Strong flavor	(1) Off-flavored materials	(1) Check storage of materials for foreign material
	(2) Poor flavoring materials	(2) Use only top quality flavors
	(3) Cakes burned or overbaked	(3) Exercise care in baking
Lack of flavor	(1) Insufficient salt in formula	(1) Increase salt content
	(2) Poor flavor combination	(2) Use proper flavor blends
	(3) Poor quality flavoring materials used	(3) Use only top quality materials
Heavy cakes	(1) Over or underbeaten eggs	(1) Beat eggs to a wet peak
	(2) Overmixing after flour has has been added	(2) Fold flour in just enough to incorporate
	(3) Too much sugar	(3) Balance formula
	(4) Too high in baking temperature	(4) Regulate temperature
Coarse grain	(1) Cold oven	(1) Regulate temperature
	(2) Overbeaten whites	(2) Whip to wet peak
	(3) Insufficiently mixed batter	(3) Fold until smooth
Tough cakes	(1) Overmixing ingredients	(1) Mix properly
	(2) Excessive sugar content	(2) Balance formula
	(3) Baked too hot	(3) Regulate temperature
	(4) Flour content high or wrong type flour used	(4) Balance formula. Use soft wheat flour
Cakes dry	(1) Low sugar content	(1) Balance formula
	(2) Overbaking	(2) Lessen baking time
	(3) Eggs overbeaten	(3) Whip to a wet peak
	(4) Flour content too high	(4) Balance formula

then scoured thoroughly with an efficient detergent. An angel food cake was then made using this bowl. The cake volume was about one inch high. This bowl had to be scoured 7 to 8 times after each baking with a detergent before the volume of the angel food cake returned to normal.

Fig. 36 shows the high percentage of fat contained in the fine fraction which was air separated from a regular cake flour. The removal of this high fat fraction caused the volume of the angel food to be increased.

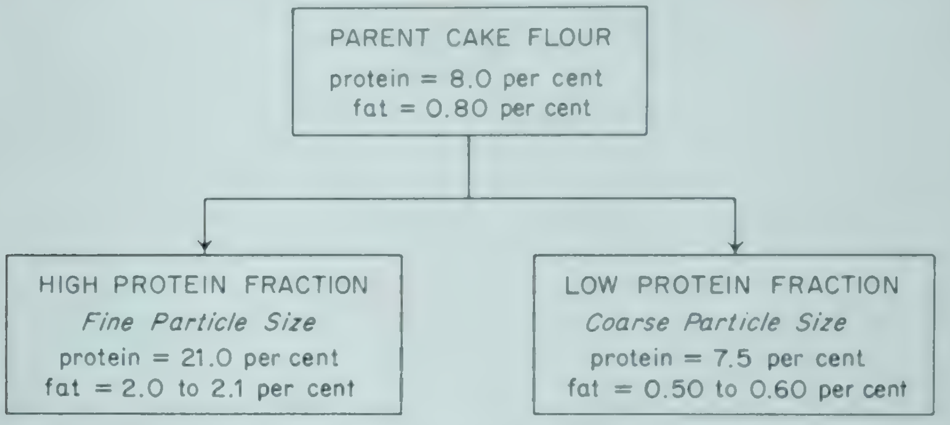
PARENT CAKE FLOUR
protein = 8.0 per cent
fat = 0.80 per cent
HIGH PROTEIN FRACTION
Fine Particle Size
protein = 21.0 per cent
fat = 2.0 to 2.1 per cent
LOW PROTEIN FRACTION
Coarse Particle Size
protein = 7.5 per cent
fat = 0.50 to 0.60 per cent

Fig. 36. Protein and Fat Distribution in Fractions of Air-Classified Cake Flour

The use of suitable starches such as wheat starch in quantities as high as 20 and 30 per cent lowers the protein of the flour and decreases the fat content, both causing an increase in volume.

Flour made from southwestern hard winter and northwestern spring wheats, when ground to a particle size approaching that of cake flour or slightly finer, can be used in the production of angel food and other type cakes. It is no longer necessary to rely on soft wheat for the production of cakes.

Since the angel food cake pan cannot be greased, the pan removal requires a different technique. The pan should be inverted, allowed to cool thoroughly, and then, if necessary, a knife run between the edges of the cake and pan to remove the cake.

Formula and method of preparing sponge cake are given on the next page (Anon. 1953).

Preparation of Sponge Cakes

Mr. Ray Thelen (1957) gives us the following comments on ingredients and formulating of sponge cake.

"**Ingredients.**—The first requisite for making sponge cakes is top quality materials of the type specially suited for foam type cakes. Perhaps the most im-

SPONGE CAKE

Ingredient	Lbs.	Oz.	Percentage*	Method
Whole eggs	5	5	21.75	Heat to 100° to 110°F. in water bath. Whip until light
Egg yolk		15	3.875	
Sugar	7	½	28.875	
Invert sugar		12½	3.25	
Salt		3	0.75	
Liquid milk	3	12	15.375	Add, just barely stirring into beaten mass
Flavor	To taste			
Flour	6	4	25.625	Fold in, mix just enough to incorporate
Baking powder		2¼	0.50	
Totals	24	6¼	100.00	

* Percentage figured on total batter weight being 100 per cent. Scale 8 inch cake tins—10 ozs. Bake at at 385° to 400°F.

Formula and method of preparing batter for pound cakes is as follows (Anon. 1949).

POUND CAKE—CREAMING METHOD

Lbs.	Oz.	Ingredients	Per cent[1]	Method
4		Cake flour	73	Cream together at medium speed until light and fluffy
		Powdered milk	7	
2		Regular type shortening	36	
1		Butter	18	
6		Granulated sugar	109	Beat together until light. (Similar to sponge cake batter). Then fold into above
3		Whole eggs	55	
	3	Salt	3½	
2	8	Water	45	Add to above mixture
	½	Vanilla	½	
1	8	Cake flour	27	Aerate well by sifting. Then add to above and mix until batter is smooth
20	9½	Total batter weight (329½ oz.)		

Important. Have all ingredients at approximately room temperature so that the finished batter will be between 72°F. and 78°F.

[1] Per cent figured on the basis of total flour weight being 100 per cent

portant ingredient that goes into the make-up of sponge cake is the eggs. Therefore, it is necessary that we secure egg products having a high solids content and the solids are to be of good quality."

Dried whole eggs are rapidly replacing liquid.

The flour best suited for sponge cake production is a high sugar carrying and high moisture carrying, soft winter wheat product.

Sugars to be employed: A fine granulated. If hygroscopic sugars are to be used, they should be of the best quality obtainable.

Milk, regardless of the type employed, should be pure, having a good clean flavor.

Butter or margarine, if employed, should be of high quality.

The baking powder should be of the type which will not release its gases at temperatures below 100°F., as the average batter temperature of a commercial sponge is approximately 90° to 95°F.

Formulating.—The basic formula for sponge cake consisting of 10 parts of sugar, 10 parts of egg material, and 6 parts of flour, salt and flavor to suit consumer taste, which is actually not a desirable sponge cake, may be used as a basis for developing commercial sponge cakes. To convert the basic formula into a suitable commercial sponge cake the following rules may be employed:

For each additional pound of flour to be added to the basic formula, it is necessary to wet it with one pound of liquid and to sweeten and tenderize the addition of flour and liquid you may add 12 to 16 oz. of sugar.

If the egg material of the basic formula is not sufficient to take care of the aeration of the batter having the added weight of the flour, liquid and sugar of the commercial formula, it will be necessary to add ¼ to ½ oz. of baking powder for each 1 pound of flour. The above leavening recommendations apply only to batters in which the egg and sugar materials have been heated. Should the sponge batter be whipped up cold, it will be necessary to increase the amount of baking powder in order to produce cakes having the desired volume. As an example, batters whipped at temperatures 90° to 100°F., including the recommended amount of leavening material, will produce cakes having approximately 30 per cent more volume than the same formula assembled at 60° to 70°F.

For making a fat type sponge you may add approximately 4 oz. of melted butter or margarine for each 2 lbs. of egg material in the formula.

Mixing.—For best results whip equal parts of egg material and sugar. Any sugar over and above the weight of eggs may be dissolved in the liquid of the batch and added before or alternately with the flour.

The egg material and sugar, for peak results, may be heated to 110°F. before whipping. If for any reason it is desired that the batch be whipped cold and frozen eggs are used, the egg material should be heated to approximately 110°F. to insure the liquefying of the oil of the egg.

Following are some of the variables which control the whipping of sponge batters and make it impossible to set a definite time for mixing sponge batters to the desired consistency: quality of egg; the temperature of the egg and sugar mass at the time of whipping; the size of the mixing bowl; the type of agitator; speed of the mixer, and the size of the batch being whipped.

The consistency of the egg and sugar mass when properly aerated should be such that it will hold for approximately 30 seconds the track or crease made by drawing a knife or spatula through the batter.

When you feel that the whipped mass has reached the proper consistency, you may measure it in a container of desired size and weigh it making certain that the batter weight in the container is exactly the same from day to day. The liquid, flour and other variable ingredients which may be used are to be added to the whipped mass and folded in thoroughly but carefully as any over-mixing will result in cakes lacking volume and the possibility of their being tough and very unappealing."

Preparation of Chiffon Cake

The golden chiffon cake is a good example of this type and can be made with the formula on the next page and suggested method of preparation (Anon. 1949).

Creaming Shortening and Sugar

Before hydrogenated shortenings were developed, butter was creamed with sugar to incorporate air and thus leaven the cakes. Even today,

GOLDEN CHIFFON CAKE

Lbs.	Oz.	Ingredients	Per cent	Method
3	6	Cake flour	100	Blend together by sifting
	2¾	Baking powder	5	
	1¼	Salt	2⅓	
2	5	Granulated sugar	68	
1	12	Liquid vegetable Oil (see note below)	52	Add to above and mix on medium speed until smooth
1	12	Egg yolks	52	
2		Water	60	
	6	Water	11	Add slowly to above and thoroughly incorporate
	¾	Vanilla flavor (high grade)	1¾	
	4	Lemon juice	7½	
	4	Grated lemon rind	7½	
3	8	Egg whites	104	Place in another mixing bowl
2	5	Granulated sugar	68	Beat until stiff
	½	Cream of tartar	1	Then add above mixture to "beaten" eggs and mix only enough to lightly incoporate.
18	3¼	Total batter weight (291¼ oz.)		

Important. Have all ingredients at approximately room temperature so that the finished batter will be between 72°F. and 78°F. *DO NOT OVERMIX*

butter can replace the hydrogenated shortening partially, or totally, resulting in better flavored cakes. Downside-up cake, yellow cake, golden yellow cake, gold cake, golden pound cake, gold cream cake, Madeline cake, rum cake, rum torte cake are examples of this type. The golden pound cake and several others have the shortening and sugar creamed together thus incorporating air. Air is incorporated at another stage of mixing by whipping the eggs and granulated sugar together.

The methods of making these cakes are all very similar, and we shall give but one where the sugar and shortening are creamed together. We will present the formula of an orange-date layer cake wherein the shorten-

ORANGE-DATE LAYER CAKE

Lbs.	Oz.		Ingredients
6	4	Brown sugar	Cream approximately 5 minutes, medium speed (creaming speed)
1		Butter	
1		Emulsifying shortening	
	2½	Soda	
	2	Salt	
1		Ground dates	
2	4	Whole eggs	Add gradually
4		Sour or buttermilk	Add
5		Cake flour	Add
1		Ground oranges	Add last
21	12½	Total weight	

Scale off and bake as soon after mixing as possible.
Scale 8 inch layer—12 ozs.
Scale 7 inch layer— 8 ozs.
Bake at 360° to 370°F.

ing, butter and brown sugar are creamed for five minutes, thus incorporating air. We present this formula because butter is used in it (Anon. 1953).

Mixing Under Pressure

Equipment has been developed by three companies for mixing cake batters under air pressure. The machines of the American Machine and Foundry Co. and another from E. T. Oakes Corporation have been described in another chapter of this book. In this section a very ingenious machine marketed by the Syko Engineering Corporation of Kansas City, Missouri, will be described. This is known as the "Whisk" machine.

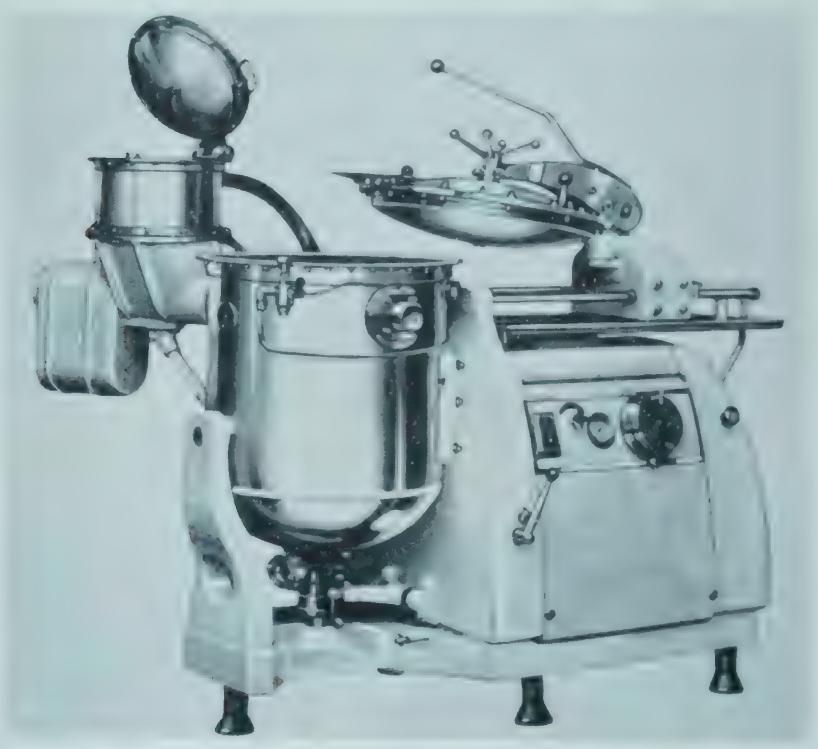

FIG. 37. MODEL 200 MORTON WHISK WITH FLOUR HOPPER

The small bowl at extreme left is a flour bowl for angel food cake. The large bowl is for mixing.

Mr. George G. Young (1959) president of Syko Engineering Corporation, gives instructions on operating, general rules to follow, and some typical formulas.

> In operating the unit, ingredients are scaled into mixer bowl. Pressure lid is applied, air (5 to 22 lbs. per sq. in.) is introduced, and the machine started.
>
> Mixing is accomplished by three rows (six to a row) of rod-shaped beaters

Center row is stationary and outer two are mounted on a horizontal shaft hooked to a $7^{1}/_{2}$ h.p. motor that also operates built-in air compressor. Mixing time is pre-set for low (60 r.p.m.), high (240 r.p.m.) or low-high blending.

When producing angel cake batter, for example, all ingredients except flour are introduced into mixing bowl. Latter is charged into 25-lb.-pressure-sealed hopper for sugar-feeding to bowl. After air pressure (22 lb.) is applied and machine started, an air valve kicks in high-speed timer for a two-minute mix. Then second timer operates low-speed mixing for about one-half minute, with flour being augered in. When mixing is completed, a button is pressed to open a self-locking, safety type discharge valve for air-delivery of finished batter through twelve feet of Tygon tubing to hopper of depositing machine.

In making sponge and other type cake batters, all ingredients are dumped into bowl for a two-minute mix at high speed. Sponges take 22 lb. air pressure, other batters 12 to 13. Marshmallow, under 20 to 22 lb. pressure, is whisked out of the machine after a 3 to $3^{1}/_{2}$ min. high-speed mix.

The general rules to follow in the operation of the Morton Whisk machine are given below:

GENERAL RULES

	Air Pressure, Lbs.	Mixing Time
Sponge cake	15 to 22	2 to $2^{1}/_{2}$, Minutes variable to formula
White layer	8 to 14	$1^{3}/_{4}$ to $2^{1}/_{2}$ variable to formula
Yellow layer	8 to 12	$1^{3}/_{4}$ to $2^{1}/_{2}$ variable to formula
Devil's-food layer	10 to 13	$1^{3}/_{4}$ to $2^{1}/_{2}$ variable to formula
Devil's-food cups	10 to 13	$1^{3}/_{4}$ to $2^{1}/_{2}$ variable to formula
Yellow cups	8 to 12	$1^{3}/_{4}$ to $2^{1}/_{2}$ variable to formula
White cups	8 to 14	$1^{3}/_{4}$ to $2^{1}/_{2}$ variable to formula
Spice layers and cups	10 to 13	$1^{3}/_{4}$ to $2^{1}/_{2}$ variable to formula
Loaf cake	10 to 13	$1^{3}/_{4}$ to $2^{1}/_{2}$ variable to formula
Pound cake	5 to 8	$2^{1}/_{2}$ to $3^{1}/_{4}$ variable to formula
Angel food cake	22 to 24	2 min. high; 45 sec. low variable to formula

The above is only a guide and the continued use of the machine will enable the operator to achieve the best efficiency by trying the variations either up or down.

To open the grain in the cake, more air pressure is used.

To close the grain in the cake, less air pressure is used.

In putting into production any formula that has not been used in the Whisk before, automatically, there is an addition of at least 10 per cent more water or the mixes will be too stiff. Cut leavening agent to 10 per cent* because your machine will take care of that.

It is to be borne in mind that the addition of water dilutes the formula. Water is a toughening agent and if in excess of the above-mentioned percentage, compensation should be made to keep the formula balanced by adding at least four ounces of sugar for every pound of water that is added, but up to the above percentage it is not necessary.

If the pressure does not rise to the desired poundage, there is a leak either in the lid or packing gland on the shaft.

Keep the gasket clean to keep the lid from sticking. Some typical formulas for use in this mixer are as follows:

---

* It has been our experience that leavening has been cut as much as 50 to 60 per cent.

WHITE LAYER CAKE

	Lbs.	Ozs.
Cake flour	23	2
Oil	1	4
Granulated sugar	24	6
Emulsifier		5
Whole eggs	3	2
Whites	12	8
Emulsified shortening	7	13
Baking powder		14¼
Salt		8
Milk powder	1	4
Water	18	12
Invert	2	14
Glucose	2	14
Total weight	99	10

13 pounds pressure
Mix 2 minutes at high speed
Temperature 68° to 70°

SPONGE CAKE

	Lbs.	Ozs.
Cake flour	27	14
Granulated sugar	28	14
Whole eggs	18	9
Yolks	7	4
Baking powder		5½
Baking soda		5½
Salt		6
Milk powder	2	1
Water	17	3
Cream		11
Invert	2	1
Total weight	105	10

22 pounds pressure
Mix 2 minutes at high speed
Temperature 72°
Jelly roll—2 lbs. 14 oz.

The incorporation of air makes it necessary to reduce the leavening agent from 50 to 60 per cent. This is a very interesting machine and represents a great advance in the processing of cake batter. Other gases could be used in place of air. The results that could be obtained with carbon dioxide may be extremely interesting because the solubility of carbon dioxide is much greater than air and in all probability this might result in further reduction of baking powder. The use of nitrogen might be extremely interesting. It would be of interest to know what would happen if unbleached cake flour were used and chlorine at the right level introduced into the mixing bowl along with the air. Whether or not this would bleach the cake flour or the chlorine would be taken up by other

YELLOW LAYER

	Lbs.	Oz.
Cake flour	60	
Oil	1	
Granulated sugar	63	
Emulsifier		9
Whole eggs	19	
Egg whites	9	
Regular shortening	12	
Emulsified shortening	7	
Baking powder	2	8
Salt	1	7
Milk powder	6	12
Water	50	
Vanilla		9
Invert	2	
Egg color		3
Extrin		1
Lemon Flavoring		1$^1/_2$
Total weight	235	2$^1/_2$

8 to 12 lbs. pressure
Mix 1$^3/_4$ to 2$^1/_2$ minutes

ingredients is all problematical, but certainly these things are worth investigation.

100 per Cent Air Leavened Bakery Products

Butter creamed icings are a very simple, yet very delicious type of icing. A formula for this type of icing is given below (Anon. 1953):

BUTTER CREAM ICINGS

Butter Cream (Smooth) (For icing and decorating Birthday Cakes)
Cream together for about 5 minutes (second speed)

7 lbs.		Powdered sugar
3 Lbs.		Shortening and butter
	12 Ozs.	Powdered milk
	10 Ozs.	Egg whites

Add to above and cream 2 to 3 minutes (until smooth)

1 Lb.	8 Ozs.	Butter or shortening (melted to 100°F.)
	8 Ozs.	Peanut Oil (or other vegetable oil)

This butter cream sets with a thin crust, but is light and ices perfectly smooth.

In summer, the addition of 1 oz. of gelatine dissolved in 8 ozs. of water and heated to 140°F. will give the cream more stability for decorating.

Many people prefer a butter cream icing on a wedding cake because of eating quality. In such a case, the cake will have a creamy rather than a white color, characteristic of wedding cakes. A wedding cake iced with butter cream and decorated with a modified Royal or other white icing has a very attractive appearance.

Variations of this same type of icing may be made by incorporating bitter chocolate, caramel and other types of flavoring.

Another type of air leavened icing is represented by marshmallow icing. This depends upon gelatin to incorporate the air.

Other products, such as pectins, modified starches, various gums are also capable of incorporating air into this type of icing. Formula for this type of icing is given below (Anon. 1953):

STOCK MARSHMALLOW

Boil to 225°F.:		
10 Lbs.		Sugar
4 Lbs.		Glucose
3 Lbs.		Invert sugar or honey
3 Lbs.		Water
Dissolve together and add:		
	6½ Ozs.	Gelatin (good grade)
1 Lb.	8 Ozs.	Hot water
Let cool.		

This stock is kept on hand and used as needed. When marshmallow is required, just take the desired amount of stock, warm and beat. Add vanilla to suit. Use marshmallow directly after beating.

Aeration of Flour

This is a very minor method of incorporating air and the amount of air incorporated is indeed very small but nevertheless the repeated sifting of flour does incorporate small quantities of air. The amount incorporated is so small that it does not deserve any lengthy discussion in this chapter.

Certain formulas have been given to illustrate the different methods of incorporating air. Any of these formulas can be changed to produce different flavored cakes, such as the addition of cocoa, orange and pineapple, candied pieces, nuts, etc.

In closing this chapter, it should be noted that the ingredient manufacturers have made rapid progress in perfecting and standardizing ingredients for use in air-leavened bakery products.

The major variables to change in an angel food are the egg albumen and the quality of the flour. In other foam-type cakes, the quality can be changed by increasing egg solids and shortening content. The use of some butter in place of part of the shortening is a very effective means of improving flavor.

Sugars are exceedingly important ingredients. By varying the percentage changes in flavor, richness, keeping quality, tenderness, texture and color of crust can be secured.

Flour has undergone rapid changes for the improvement in quality. Cake flour running as low as 6½ per cent protein, made out of the southwestern hard wheat, can be obtained, producing excellent cakes.

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Samuel A. Matz

Formulations and Procedures for Unleavened Bakery Foods

The most important representative of this type of goods is pie crust. Puff pastry and certain types of cookies are also unleavened in the sense that no chemical or biological leavening agents are included in the formula, although an appreciable volume increase occurs in puff pastry during baking. It is true that some formulas for pie crusts call for small amounts of baking powder, but the conventional and typical recipe omits such ingredients and they are not required to secure finished products having desirable eating qualities.

Pie crusts are low in moisture and high in fat. This ratio of ingredients, together with the method of preparation, prevents the formation of a continuous gluten network throughout the dough mass and results in baked products that are more or less friable or flaky. A porous structure such as typifies all leavened bakery products is not desired because pie crusts must support and retain without leakage fillings of moderate viscosity and high moisture content.

Pie crusts are generally divided into three classes based upon their "flakiness." The latter term can be defined loosely as the tendency of the crust to separate into strata or layers when it is broken. Flaky or long-flake crusts when broken tend to exhibit fracture along different lines at different levels, and to show separation in layers parallel to the surface. Mealy crusts can be broken in a straight line and show a fracture surface more like that of a cookie. Short-flake or flaky-mealy crusts exhibit characteristics intermediate between the two extremes.

The flaky crust is esteemed by connoisseurs and by trade experts, but it shows the abuse of handling more quickly than the mealy type and it poses difficulties in serving. It is also more difficult to process than the mealy type. Mealy crusts can be cut readily, usually support fillings adequately, and are not particularly sensitive to processing conditions. Most manufacturers catering to the general public make pies with mealy-type crusts. Home recipes are generally designed to produce flaky crusts, but most packaged mixes yield the mealy variety.

The basic formula for pie crusts requires flour and water for structure formation, shortening to provide the desired textural qualities, and salt to enhance the flavor. Usually sugar is added to insure adequate coloration. The amount of water used, the kind of shortening, and the method of mixing are the chief determinants of crust characteristics.

The weakest flour available is suitable for pie crusts. Any factor tending to strengthen the gluten structure is to be avoided. In practice, this means that the flour used in pie crusts should be unbleached with a protein content of 7.0 to 8.5, ash content of 0.38 to 0.48 per cent, and a MacMichael viscosimeter reading of 30 to 40 degrees (Cook 1953). Struckmann (1956) recommends even narrower limits of 7.0 to 7.25 per cent for protein, and 32 to 36 degrees for viscosity. The flour should be milled from a soft white winter wheat and should be slightly granular. Soft red winter wheats yield somewhat stronger flours which may or may not be satisfactory for the purpose, depending upon how critical the finished product requirements are.

Shortening for pie crust doughs is used at a level of about 70 to 75 per cent (FWB) in household recipes, about 50 to 60 per cent in commercial pie crusts, 50 per cent or less in doughs made with liquid shortenings, and as little as 35 per cent in fried pie doughs. The type of shortening determines the amount which must be used. Elling (1952) listed the following shortening values for some common fats:

Totally hydrogenated shortening	100
Partially hydrogenated shortening as generally used in bakeries	110
Partially hydrogenated lard	110
Open kettle plasticized lard	125
Special grainy type lard	130–135
Oil	150

These shortenings were evaluated by preparing crusts from a uniform recipe, varying only the type and quantity of fat. Woerfel (1959) claims that vegetable oils are generally lower in shortening value than is lard. Lard is frequently called for in household recipes and some prepared mixes include hydrogenated lard from which part of the lard oil has been removed. Lard is also much used commercially and the tough, fibrous variety is preferred over the soft, grainy type. The former gives a short and tender crust without greasy effect. Emulsifiers should not be used in pie crust shortenings.

Salt is used at levels of from 1.5 to 4 per cent of the flour weight. It should be dissolved in the absorption water since its solution may be excessively slow at the temperatures and water concentrations present in pie dough.

Sugar, corn syrup, or dextrose are commonly used in proportions of about 3 to 8 pounds per 100 pounds of flour. These amounts give adequate coloration without contributing a sweet taste to the crust. Sometimes the sugars are dispersed in the absorption water along with the salt and the milk solids, if the latter are used. Whey or nonfat milk solids can be included for much the same purpose as sugar. That is, the lactose in whey and milk powder contributes to the browning. Spray dried milk solids are preferred to roller dried material. Wheat or corn proteins may be added to insure good machinability of the dough and crispness of the finished product. Propionates are frequently included in the formula at about the 0.2 per cent level to retard mold formation.

The flaky crust is obtained by mixing all of the shortening with all of the flour for a period just sufficient to reduce the shortening to small lumps. The recommended size for the fat pieces varies somewhat according to the authority consulted and the type of shortening employed. Generally all of the ingredients are refrigerated, and in any case the flour and water are brought to 35 to 40° F. before mixing. The doughs are invariably refrigerated before being rolled and cut in order to keep the shortening particles discrete.

In preparing doughs for mealy crusts, the shortening may be completely dispersed in the dough. Consequently, processing conditions are less critical. It is usually convenient to mix the flour-shortening blend until the fat is completely absorbed and the flour particles are coated. Refrigeration of ingredients and doughs is of no particular value in this case.

Large amounts of scrap dough are generated in the cutting of pie crust circles, and the problem of economically disposing of this scrap is of great concern to pie manufacturers. Most authorities recommend that scrap dough be blended into fresh dough in quantities not exceeding 50 per cent of the total. Use of scrap dough in this manner is essential in most operations, but it does adversely affect texture. Some bakers restrict the use of scrap blends to bottom crusts, while other operators believe that it is more desirable to take advantage of the greater dilution of scrap which is possible when it is blended into all of the crust mixes.

The two steps common to nearly all pie dough mixing processes are: (1) blending the shortening and the flour until the fat has reached the desired degree of subdivision, and (2) adding the water and water-soluble ingredients to the fat and shortening mixture and agitating until the water has been absorbed. As stated previously, flaky crusts require a short first stage which leaves the shortening in the form of discrete lumps while mealy crusts are thoroughly mixed during the first stage so that the flour particles are completely coated by the fat. Intermediate types of crusts may be prepared either by reducing the shortening to very small lumps, e.g., about the size of peas, or by a two-stage addition of fat during one stage of which the fat is thoroughly dispersed while in the other step mixing is carried only to the point where the fat has been broken down to fairly small uniform particles.

Most processing instructions call for the water to be chilled. Not infrequently the flour is also brought to refrigerator temperatures before use. In addition, the dough itself is usually chilled for several hours after mixing. This cool rest period allows the water to distribute itself more thoroughly in the dough mass and hardens the shortening so that it is less likely to liquefy during subsequent handling and shaping operations. These chilling steps are particularly important in the manufacture of dough for long-flake crusts. Mealy-type doughs should come out of the mixer at about 65°F. and be held (covered, of course) at this temperature for about 3 to 4 hours.

Elling (1952) gives a formula and procedure for making a 221 pound batch of long-flake dough suitable for use during the warm weather months. He indicates that the same formula can be adapted for producing short-flake or mealy crusts if the processing techniques are changed appropriately.

Long Flake Crust

(1) Mix smooth but do not cream:
45 lbs. steam rendered lard
15 lbs. partially hydrogenated vegetable shortening

(2) Add the following ingredients to the above and mix until the fat is in pieces the size of walnuts:
100 lbs. soft pastry flour at refrigerator temperatures
6 lbs. nonfat milk solids

(3) Add the following to the flour, fat, and milk solids and mix just enough to blend thoroughly:
38 lbs. ice water
4 lbs. salt
3 lbs. corn sugar

Struckmann (1956) described the production of doughs yielding a short-flake crust suitable for fruit pies.

Fruit Pie Dough

(1) Place in an arm-type mixer and blend the following together until the shortening and flour are well incorporated:
100 lbs. flour
25 lbs. margarine or low melting point shortening

(2) Continue to mix the flour and margarine until it attains the appearance of a coarse streusel with no raw flour spots in evidence, and then add 45 lbs. of lard.

(3) After mixing has reduced the lard to chunks about the size of eggs, add:
4 lbs. spray skim milk powder
3 lbs. salt
2 lbs. corn sugar dissolved in
28 lbs. ice cold water

(4) Continue the mixing until all of the ingredients are thoroughly dispersed. Stop mixing when the pie dough is dry with no wet spots evident and the shortening is in tiny lumps well distributed throughout the entire batch.

Struckmann also gave a formula and procedure for making a mealy type crust especially suitable for small individual pies and custard shells.

Dough for Mealy Crusts

(1) Place in mixer and blend thoroughly:
100 lbs. pie flour
45 lbs. lard
20 lbs. margarine or low melting point shortening

(2) When the above is thoroughly mixed and no raw flour spots are visible, add:
3 lbs. spray dried nonfat milk solids
4 lbs. corn sugar, and
3 lbs. salt dissolved in
24 lbs. ice water

(3) Continue to mix until the water has been completely taken up.

Frazier (1947) recommends using 6¼ oz. dough for the bottom crust and 5¼ oz. for the top crust of nine-inch pies containing 26 to 28 oz. filling. Crusts for nine-inch cream pies should be scaled at seven ounces. However, Elling (1952) suggested a six and one-half ounce scaling weight for both crusts of nine-inch pies and four and one-half ounces for both crusts of eight-inch pies. The filled pies are baked 28 to 32 minutes at 450°F.

There is a considerable difference of opinion regarding the merits of "washes" for the top crusts of pies. Washes of egg or milk, or combinations of these, result in glossy and relatively dark crusts. Some bakers regard this appearance as highly desirable while others consider it to be somewhat artificial. Struckmann (1956) suggested the application of a spray of skim milk to the top crust of pies just before they enter the oven. This gives a golden brown crust color and a drier and crisper texture. Cook (1953) indicated that some bakers spray the crust with melted shortening to give a flake on top of the product.

FRIED PIES

Fried pie crusts present some special problems. The all-important characteristic in this case is structural strength since the crusts of fried pies are not supported by pans during their transportation from the factory to the point of consumption. According to Keathley (1956), the basic formula for fried pie dough is:

100	lbs.	pastry flour
35	lbs.	vegetable shortening
35	lbs.	water
3	lbs.	salt
4	lbs.	corn sugar

Lard is not recommended for the dough or as the frying fat. Mixing procedures and equipment are similar to those used for baked pies except that fried pie doughs may be mixed a little longer and to a smoother consistency than those used for baked pies. The securing of flakiness is generally not a primary consideration with these products.

Dietrich (1957) has given a specific formula and procedure for fried pie crusts.

Dough for Fried Pies

(1) Blend together thoroughly:
100 lbs. pie flour
25 lbs. hydrogenated shortening
100 lbs. dough scraps from previous production
(2) Blend together the following, and then add to the above:
30 lbs. water (variable)
2 lbs. salt
(3) Add and mix until a smooth dough results:
1 lb. corn sugar (optional)
3 lbs. wheat or corn protein
3 oz. mold inhibitor

This dough can be made up immediately if desired, but holding does not cause it to deteriorate. After mechanical or hand scaling into pieces of desired size, the dough is sheeted by mechanical rollers or other means. Dietrich described some ingenious automatic panning and forming devices for preparing fried pie crusts, but these machines are apparently not available commercially.

About $1^1/_2$ oz. of dough to 2 oz. of filling is the recommended scaling weight for fried pie crusts. The pies are fried submerged at a temperature of 375 to 380°F. for about three minutes and then are thoroughly cooled by forced air before wrapping.

Dietrich described variations in processing of fried pies which yield special characteristics. In one operation, fried pies were dipped into a kettle of constantly boiling water immediately after frying. This set the crust and floated off excess cooking fat. Such pies kept well during the summer months and had a slight gloss. In another variant process, the crusts were made up with high protein spring wheat flour. Then, prior to frying, the pies on the screen were dipped quickly into boiling water and then immediately transferred to the frying fat. Pies prepared by this method had less greasiness of crust than most.

Causes of Faults in Pie Crusts

For trouble-shooting crust problems, the following suggestions (Anon. 1958) may be helpful:

(1) Excessive shrinkage of crusts may be caused by:
  (a) Not enough shortening.
  (b) Too much water.
  (c) Dough worked too much.
  (d) Flour too strong.

(2) Crust not flaky. May be caused by:
  (a) Dough mixed too warm.
  (b) Shortening too soft.
  (c) Rubbing flour and lard too much (overmixing).

(3) Bottom crust soaks too much juice. May be caused by:
  (a) Insufficient baking.
  (b) Crust too rich.
  (c) Oven too cool.

(4) Tough crusts may be caused by:
  (a) Flour that is too strong.
  (b) Overmixing the dough.
  (c) Use of excess water.

(5) Soggy crusts may be caused by:
  (a) Not enough bottom heat.
  (b) Oven too hot.
  (c) Using a filling that is too hot.

PUFF PASTRY

Puff pastries, in their conventional form, are not very well adapted to mass production and so are, in the strictest sense, outside the scope of this volume. However, a brief discussion of these foods is included at this point for general information purposes.

The principle underlying the preparation of puff pastry is very similar to that on which the manufacture of true Danish pastry is based. Layers of fat are interleaved between layers of dough so that upon baking a separation of dough strata occurs. However, in Danish pastry yeast-leavening action plus the inclusion of auxiliary ingredients result in a soft and porous structure in the baked dough layers. Puff pastry doughs yield a very open network of crisp and flaky layers. In the preparation of both of these products the main precaution to be observed is the maintenance of cool doughs so that the shortening will not melt and then be incorporated into the crumb.

A traditional method of preparing puff pastry dough is illustrated by the following method and procedure.

Dough for Puff Pastry

(1) Mix a dough consisting of:
5 lbs. bread flour or a mixture of 8 parts bread flour and 2 parts pastry flour
2$^1/_2$ oz. salt
2$^1/_2$ lbs. special puff paste shortening
1 lb. water

(2) Roll the dough out into a rectangular shape and place it in the refrigerator. After the dough has cooled down, sheet it out to one-third inch in thickness, retaining the rectangular shape as much as possible.

(3) Spread two and one-half pounds of puff pastry shortening over two-thirds of the sheet and fold it over so that three layers of dough are separated by two layers of shortening. Roll the mass out to a thin sheet and again fold into three layers.

(4) Refrigerate for about an hour and then roll out and fold over as before. Repeat the sheeting and folding and then refrigerate once more. For best results, the sheeting and folding should be repeated once or twice after this refrigeration stage.

(5) After cooling down the dough, cut it into the desired shapes and bake at 350° to 375°F. for 35 minutes.

Development of highly specialized puff pastry shortenings has allowed the use of procedures which do not include the tedious rolling-in steps of the traditional method.

Rapid Puff Pastry Method

(1) Mix together just enough to incorporate the shortening:
10 lbs. bread flour
2 lbs. puff pastry shortening (cold)
3 oz. salt

(2) Add six pounds (variable) of water at about 40°F. and mix with the batter beater at high speed until the dough forms a ball. Scrape the dough from the bowl sides.

(3) Add two pounds of cold water and develop the dough.

(4) Scrape the dough away from the sides of the bowl and add eight pounds of cold puff pastry shortening. Mix at low speed until the shortening has just been blended in. This is the critical step and overmixing here will destroy the puff pastry characteristics of the product.

The special shortenings developed for puff pastries are generally compounds of meat fats, vegetable oils, water, and salt. Lecithin and monoglycerides may be included. Sometimes the water is replaced by skim milk or cultured milk. Butter was originally the shortening of choice for puff pastries, but many of the new compounds improve considerably on the performance characteristics of the dairy product.

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SECTION II

Equipment and Engineering

CHAPTER 13

A. Bruce Corn

Receiving, Storage, and In-Plant Conveying of Raw Materials

The principal factors that govern the planning and construction of receiving, storage, and distribution facilities within a bakery are sanitation requirements, and efficient, economical methods of transporting the various ingredients from the receiving dock into storage, and from storage to the point where they are incorporated into the finished product.

This chapter will deal with the subject in two parts; sanitation requirements that must be met to produce optimum storage conditions, and methods and equipment necessary to implement an efficient material handling program within the bakery.

SANITATION REQUIREMENTS

Building Design and Preparation

The storage areas should, under ideal conditions, have floors, ceilings, and walls built of such materials and maintained in such condition as to deny access by insect and rodent life to any point within or behind the face of these building elements. Similarly, all harborages adjacent to the storage areas must be eliminated to prevent the existence of places within easy reach from which rodents and insects might invade the premises. All windows and doors must be adequately screened to exclude flying insects and they must also be rodent-proofed in accordance with best practices. Specifically, hollow enclosed spaces between double wall partitions should be avoided in the construction of storage areas. Other harborages that should be avoided or eliminated include the space between the ceiling and roof of a building, the enclosure between the bottom shelf or a tier of shelves and the floor, the space between the base of machinery and the floor, and similar conditions that are conducive to infestation of a storage area. Wood floors should be maintained in such condition that all cracks are filled, and the surfaces sealed. Of particular importance is the elimination of any cracks or crevices at the point where the floor meets the walls. Concrete floors should be sealed chemically to eliminate any dusting of the surface occasioned by foot or machine travel in the aisles.

The storage areas should be well lighted and ventilated. Specific areas

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TABLE 68

RECOMMENDED INGREDIENT STORAGE CONDITIONS

Ingredient	Recommended Storage		Approximate Maximum Storage Time, °F.			Evidence of Deterioration	Remarks
	Temperature, °F.	Relative Humidity, Per cent	40 °F.	70 °	90 °		
Chocolate	70 to 90	Below 85	Indefinitely	5	Years 2	Slight rancidity after long storage; may become gray on top	The grayness known as "blooming" is caused by the fat melting and rising to the surface. This does not affect the quality of the cocoa.
Cocoanut	40 to 60	40 to 50	2	Months 1		Rancidity, yellow color, soapiness, lumping	
Eggs:							
Shell	29 to 32 (Will keep about 8 months at the above temperature	85 to 92	6	Weeks 1		Watery whites, loss of whipping strength, mustiness, off flavors	Air cells increase in size due to loss of water by evaporation. pH increases. Bacterial decomposition sets in.
Frozen	−5 to −10	Dry	..	..		Same as above	
Dry	35 to 45	20 to 30	12	Months 5	1	Flavor, odor, color	
Flour	68 to 72	65 to 75	Indefinitely	Months 6	3	Rancidity, insect infestation, lack of baking strength, mustiness	Use skids. Protect against rodents and insects.
Fruit:							
Fresh	30 to 50	75 to 95	Depends on type			Browning, softening	Bananas are an exception, keeping best at temperatures of 50° to 60 °F.
Frozen	0 to −10° (Will keep about 1 yr.)					Browning	A temperature of about 15 °F. is unsafe for storage.
Dry	70 to 90	20 to 30	30	Months 18	6	Insects, mold darkening, lumping	Dry, cool storage is a prime requisite.
Leavening agents							
Baking powder	60 to 80	20 to 30	8	Months 6	2	Lumping, loss of strength	Keep container closed when not in use. Do not keep a very large inventory on hand

Yeast (compressed)	35 to 45	. .	7 to 10 days	. .	. .	Odor and mold, slime and darkening, loss of baking strength	Get fresh delivery as often as possible.
Yeast (active) dry	40 to 70	20 to 30	18	Months 8	3	Strong odor, lack of baking strength	
Malts:							
Non-dias. syrup	65 to 75	40 to 60	. .	2 mo.	. .	Darkening	Above 85 °F. the malt darkens and loses diastatic power. At low temperatures sugar will crystallize out from the malt.
Diastatic syrup	65 to 75	40 to 60	. .	2 mo.	. .	Darkening, loss of diastatic power	
Dry	40 to 75	20 to 30	. .	2 mo.	. .	Same as above	
Milks:							
Liquid, whole	33 to 35	. .	3 to 4 days	. .	. .	Odor, taste	Temperatures above 55 °F. at time of delivery are considered unsafe.
Evaporated	40 to 90	. .	24	Months 12	6	Cream separation, sedimentation, darkened color	Cases should be turned every 30 days to prevent separation of butter fat.
Sweetened condensed	40 to 90	20 to 30	16	Months 12	. .	Brown color, grittiness, lumps	Temperatures above 100 °F. or below 0 °F. are unsafe for storage.
Dry whole	40 to 75	20 to 30	18	Months 6	1	Rancidity	Keep milk dry and covered.
Non-fat dry milk solids	40 to 75	20 to 30	24	Months 24	6	Staleness	
Mineral yeast food	40 to 90	20 to 50		Indefinitely		. . . .	. . . .
Nuts	40 to 55	75	2	Months 1	. .	Insects, rancidity	Bulk nuts are extremely susceptible to insect infestation and rancidity.
Salt	50 to 100	20 to 30		Indefinitely		. . . .	. . . .
Shortening:							
Hydrogenated	50 to 70	20 to 30	Indefinitely	Months 50-lb. container 4	2	Loss of baking value and creaming power	Moisture and heat tend to hasten rancidity. Keep containers covered when not in use.
			Indefinitely	Drums 6	4		
Lard	50 to 70	20 to 30	5 mo.	Plain 1 wk.	2 da.	Rancidity	
			Indefinitely	With antioxidant 6 mo.	4 mo.		

TABLE 68—*Continued*

RECOMMENDED INGREDIENT STORAGE CONDITIONS

Ingredient	Recommended Storage		Approximate Maximum Storage Time			Evidence of Deterioration	Remarks
	Temperature, °F.	Relative Humidity, Per cent	40°F	70°	90°		
Corn oil	30 to 75	20 to 30		Months		Rancidity	
			10	6	1		
Butter and margarine	0 to 30	20 to 30	10°F. 1 yr.	33° 2 mo.	50° 2 wks.	Rancidity	
Spices	40 to 75	20 to 30		Months		Mold, insects	Will lose flavor through volatilization.
			12	6	..		
Sugars:							
Cane or corn	50 to 100	Below 60		Years			
			4	4	4		
Powdered	50 to 100	Below 60		Months			
			10	10	10		
Brown and Maple	35 to 75	60 to 70		Months			
			10	10	..		
Honey and invert sugar	60 to 80	Below 60		Months		Sugar crystallization, formation of gas	At temperatures below 40° sugar crystallizes from the honey or invert. The syrup and molasses must be pasteurized to keep this long.
				18	5		
Corn syrup and molasses	40 to 85	Below 60		Months		Crystallization, gas formation	
			20	20	12		

should be maintained at the dry bulb temperatures and humidity levels recommended in Table 68.

Excellent detailed information on rodent and insect control is available from bulletins published by the American Institute of Baking, Department of Bakery Sanitation, Chicago, Illinois. The review of this material is recommended by anyone designing new storage areas or renovating existing ones.

RECEIVING AND STORAGE METHODS AND PROCEDURES

The receiving and storage of ingredients in a bakery covers three broad classifications; *dry storage, cold storage,* and *bulk storage.* Since packaging materials eventually come in contact with the finished product, they should be treated as ingredients. The handling of these items will be discussed under the heading of *Dry Storage.*

Receiving

Inspection of all incoming ingredients at the receiving dock is an absolutely necessary procedure because the results of subsequent good storage practices will be ruined if rodents and insects are allowed to enter the storage areas by this avenue. Both insects and mice have been found in ingredients shipments received both by rail and by truck. In order to detect these, each unit of materials received must be thoroughly inspected. Packages showing signs of mechanical damage or of tampering or evidence of insect or rodent infestation should be set aside for prompt examination of the contents. Such signs include tears, gnawed places, and insect webbing. To check internal infestation of flour it is recommended that approximately 20 bags from each car be taken from different places in the car and examined by sifting. This can be done by opening each bag and sifting approximately 1 or 2 lbs. of flour through a 30-mesh hand sieve. These flour samples should be taken from the top of the bag along the seam. Any insect contamination or other foreign material separated can then be placed in a separate jar on a bag by bag basis as tangible reason for rejecting the car.

In the case of larger particle products such as whole wheat flour, raisins, and nuts, where sifting is not possible, it is recommended that a number of containers be opened at time of receipt and that the contents be spread out on white paper. The clumps should be broken and the entire contents gone through closely in search of live or dead insects.

It is important that all ingredient examinations should be performed before the containers are brought into the storage area. The shipping containers should be checked for contamination on the outside as well as on the inside. This examination should be made immediately after the car, truck, or other vehicle is opened because many insects do not like the light and will tend to crawl into cracks or between bags or cartons where they cannot be readily found. The area immediately around the doorway, as well as both ends of the truck or freight car should be thoroughly examined with a flashlight for evidence of live insect infestation. Several bags should be lifted so that the second layer may also be checked. If more than ten live insects can be found readily in the car or truck, the shipment should be considered for rejection without further examination since it is almost certain that hundreds of insects are present. While looking for evidences of insects, bags should also be closely checked for any signs of other contamination such as rodent damage.

The foregoing discussion applies to bagged materials or ingredients in crates, boxes, drums or other containers. The examination of ingredients shipped in bulk form presents an entirely different problem.

The method of sampling these ingredients will vary depending on circumstances. Possibly the easiest way of obtaining granular samples of a bulk shipment, is by use of a large grain trier. This is a long narrow cylindrical device which has numerous openings along its length. These openings may be closed by twisting the handle at the top. The bottom end is pointed to permit insertion into the bulk material. After the proper samples have been obtained by this method, they should be sifted and inspected as described above.

Records of all examinations of all incoming materials should be kept showing the identity of the lot and the findings. Such records will serve as a history of any given supplier and will be of help in determining the frequency of detailed inspections that should be made of each supplier's shipments.

Dry Storage

The overall aim in planning proper storage of all ingredients is to insure that the raw materials will not become contaminated while awaiting use. The following procedures are recommended to produce this result:

(1) At the point where the bags, cartons, or other packages are loaded onto skids or pallets, care should be taken to brush any clinging material from their exterior surfaces. They should be neatly stacked upon clean skids or pallets and placed in storage.

(2) The storage area should be clean and should be treated with residual insecticide.

(3) A white border 18 inches wide should be painted around the perimeter of all storage areas, and should extend up from the floor on the adjacent wall ten inches. White enamel paint such as used on highway markings is often recommended for this purpose.

(4) The skids or pallets should be stored 18 inches from all walls, and if space permits, a 14-inch aisle should be left between double rows of skids. This method of storage will permit sweeping under skids.

(5) Every damaged bag or carton received, whether ingredient or packaging material should be sealed with gummed tape after making sure that foreign materials have not entered the contents by way of the opening caused by the damage to the bag or carton.

(6) Experience has shown that any material left unmoved for more than a month may develop an insect or rodent infestation, and it is therefore highly recommended that incoming shipments be tagged as to date of receipt, and that withdrawing from warehouse stock of ingredients or of packaging material be done on a first in, first out, basis.

(7) Although drums of lard and other ingredients in metal containers should preferably be on skids, there is no objection to storing them directly on the floor, provided the area is clean and the barrels are moved at least every two weeks.

(8) It is very important to make sure that no bag of ingredients comes in contact with foot traffic. All foot traffic areas must be considered dirty.

(9) Once bags or containers are opened, they should either be removed from the storage area or should be sealed to their original state.

(10) All materials and equipment not being currently used should be moved to storage facilities outside of the active storage area. There is a tendency to let inactive pan storage, standby machinery storage, and other miscellaneous storage gradually encroach upon these areas. Because such equipment is seldom disturbed, after a period of time it can develop into harborages and breeding places.

(11) In removing stored materials to the scaling area, care should be taken to clean the bags and other containers of dust on the exterior surfaces. This is necessary due to the inevitable practice of shaking the inverted bag over the dump sink or scaling container. Unless the exterior of the bags is kept perfectly clean, the transfer of dirt from the exterior surface is most likely.

Cold Storage

Adequate cool and cold storage space should be provided. Cool storage is defined as cold storage at or above 32°F. In general, the same good storage practices required in dry storage areas apply in refrigerated rooms. Materials under refrigeration should be placed in a cold room immediately upon receipt and after inspection because such materials may well have been in transit without refrigeration for some hours.

The thawing of frozen products should take place preferably in a tempering room. If this is not possible, there should be a carefully planned thawing schedule. Careless thawing at room temperature can produce off-flavors because the exterior portions of the materials in any given unit may begin to spoil before the interior core is completely thawed. This is possible because most food substances are poor conductors of heat.

All material in storage should be covered in an air-tight condition.

High humidity is objectionable in cool storage since it can cause mold growth to start. If this condition should develop, some moisture absorbent such as calcium chloride should be used to reduce the humidity.

Storage containers should never be placed directly on the floor. Wood stripping or pallets should be provided so that the first layer of containers is about 2 or 3 inches off the floor and additional stripping should be provided every 2 or 3 feet of layers. The containers should not be stacked closer to the walls than six inches and to the ceilings than twelve inches. Six inches clearance should be provided between the topmost container and the ceiling coils. Aisles should run parallel to the ceiling coils. When these coils are defrosted, the ingredient containers beneath them should be covered with a tarpaulin.

Excessive circulation of air in the storage room should be avoided. It is necessary only to gently move the air at low velocity around the containers to achieve the desired results.

Bulk Storage

Bulk storage can be divided into two classifications, granular and fluid or liquid. Although it is possible to handle the majority of baking ingredients in bulk form, economics have generally restricted the granular materials to patent and clear flour, cane and beet sugar, corn sugar and in some installations, salt. The ingredients usually handled in a fluid or liquid state include lard, vegetable shortening, cane and beet sugar, corn syrup, milk, and eggs.

In planning facilities for the storage of these ingredients, the same principal end results should be kept in mind as govern the handling of ingredients in bags, boxes, drums or tins. As stated before, every effort should be made to insure that the raw materials are not contaminated while awaiting use.

In selecting materials for the construction of bins, tanks, pipes, pumps, meters, and all other equipment the surface of which comes into contact with the ingredient being stored or transported, care should be taken to be certain that the surface is non-toxic, non-absorbent, is odorless and is durable enough to be unaffected by ordinary cleaning methods.

In designing bins, tanks, piping systems and related bulk storage and distribution facilities, the cleaning and sanitizing requirements of each element must be kept in mind.

The subject of design criteria is much too weighty to be discussed at great length in this chapter. The Baking Industry Sanitation Standards Committee, 511 Fifth Avenue, New York City, is now engaged in writing a Sanitation Standard to govern in the design and construction of such facilities. It is highly recommended that anyone interested in making an installation for handling ingredients in bulk obtain these Standards.

There are several specific examples, that should be discussed under this heading, of precautions that should be taken in addition to proper design of equipment in order to obtain best results from a bulk installation.

The possibility of lards and shortenings becoming rancid in bulk storage can be minimized by adding an antioxidant at the refinery. When storage at the bakery is for long lengths of time it is sometimes desirable to fill the head space of the storage tank with nitrogen. This procedure will provide a maximum of protection for preserving the bland flavor of fresh shortening.

In planning storage tanks for liquid cane and beet sugar, fittings should be provided diametrically opposite each other at the top of the tanks to receive a blower on one end, and an exhaust on the other. Each should be provided with a filter to prevent entrance of dust and insects. These are for the purpose of ventilating the void in the tank above the liquid sugar level, to prevent the formation of condensation. If allowed to form, condensation will dilute the surface of the liquid sugar and make it more susceptible to the action of bacteria. A blower of 50 c.f.m. capacity normally is adequate. Excessive movement of air will result in evaporation and subsequent crystallization of sugar on the surface of the liquid.

Ultra-violet lamps should be installed in the top of the tanks for the purpose of killing bacteria, yeasts and molds.

It is recommended that the 3-A Sanitary Standards of the Dairy Industry be consulted in the design of bulk handling facilities for handling liquid eggs and fluid milk.

MATERIALS HANDLING OF INGREDIENTS WITHIN BAKERY

The selection of materials handling equipment for use in transporting the ingredients from the receiving dock to storage, through the storage period, and from storage to the scaling areas demands a knowledge of the equipment that is available, its limitations as well as its strong points, a good appreciation of its eventual application, and a study of the economics involved, e.g., first cost versus benefits derived from its use.

Analysis of Equipment Required for Its Particular Application

Detailed design criteria should be prepared preliminary to selecting any item of material handling equipment. The weight and shape of loads to be handled on pallets and skids should be determined. The allowable stacking heights within the storage building should be determined. Rates of flow of conveyors, speed of travel of fork trucks and transporters, and method of shipping to be used to the bakery should be decided. Modules of pallet sizes should also be established. Other considerations are the weekly usage of various ingredients and the inventory to be carried. Special considerations should be listed, e.g., will fragmentation of granulated sugar crystals, occasioned by some methods of conveying be objectionable.

After this preliminary data is assembled, the economics of alternate methods should be worked out.

Generally speaking, sanitary considerations dictate that in selecting pallets, skids, shelving and racks, the more open the construction, the better. In this same vein, steel-wheeled warehouse carts and transporters should be avoided to prevent excessive floor wear which in turn would result in dusting of the surface.

Description of Equipment Available for Transporting Raw Materials to and From the Storage Areas

The equipment required to implement a successful material handling program in a modern bakery ranges from the conventional warehouse line of pallets, skids, warehouse carts, transporters, and fork trucks to the more specialized systems of mechanical and pneumatic conveyors, tanks, pumps and piping systems and weighing systems required for bulk handling installations. To cover the subject as intensively as possible without repetition, the warehouse equipment will be treated as a separate category. The conveyors, both mechanical and pneumatic will be described briefly, and then under separate headings each of the principal ingredients now handled in bulk will be discussed in more detail with regard to the particular type of handling equipment that should be used in each application.

Warehouse Equipment.—

(1) ***Shelving.***—Ingredient storage shelving can be made of either wood or steel construction. In either case all joints between the shelving and the vertical supports should be made tight to prevent any buildup of foreign material in cracks or crevices. All shelving should be open in the back and the space between the lowermost shelf and the floor should also be

left open. It is usually advisable if possible, particularly with steel shelving to use a type that allows vertical adjustment of shelves.

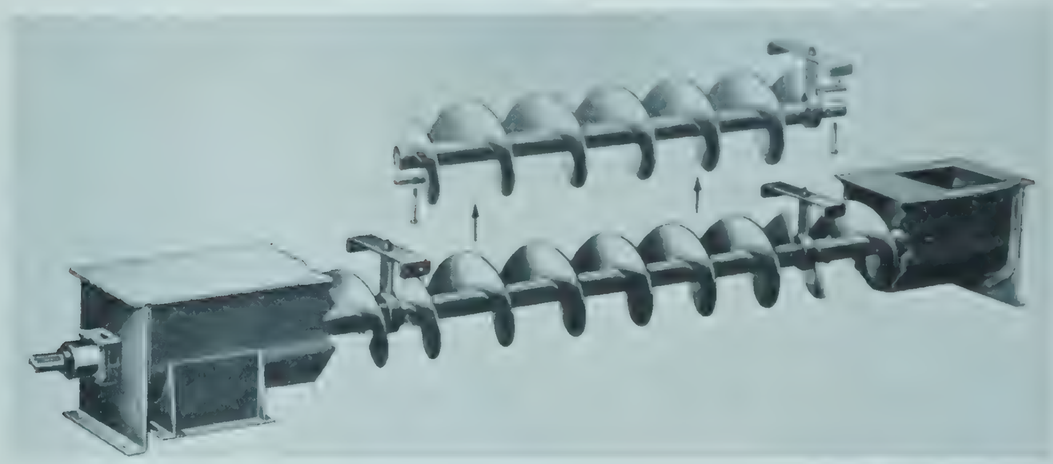
(2) ***Racks.***—Racks, as described under this heading, are used for the storage of materials in drums. They should be built of steel pipe, and the pipe ends should be sealed. The first horizontal support should be a minimum of 18 inches above the floor. The racks should be portable so they can be moved for easy cleaning of the floor area beneath them.

(3) ***Pallets.***—Pallets are simple platforms providing top and bottom bearing surfaces and a slot for insertion of the lifting device. Pallets are made of wood, steel, aluminum, expanded metal and, in some cases, a combination of cardboard and wood. The latter type has been called the "throw-a-way pallet." Pallets are made as either single-faced or double-faced units. When they are made of wood, the slats used for the facing material are spaced so that foreign materials can easily be brushed through the openings.

(4) ***Skids.***—Skids are commonly all wood, all steel, or steel and wood construction combined. They consist of platforms equipped either with runners or with four legs to hold the platforms 6 to 8 inches off the floor to provide clearance for the platform of a lift truck. Skids are sometimes constructed with only two legs provided at one end of the platform. The other two corners are then supported on small diameter wheels. A small diameter pin is positioned midway between the two fixed legs of the skid. This skid can then be moved by means of a "fifth wheel" which is used to engage the small pin referred to above. In its stored position therefore, the skid is supported by two fixed legs and two small wheels. In its portable position, it is supported by the two small wheels and the skid truck.

(5) ***Skid Truck.*** This truck consists of two small diameter wheels closely spaced together, connected to a pipe handle which the operator engages. By means of a tilting operation, the small platform atop the wheels engages the pin of the above-described "live skid." The capacity of this unit is dependent upon how much load the operator can manually pull.

(6) ***Warehouse Trucks.***—This item consists of a platform with a short blade at right angles to the platform supported on two small diameter wheels. It can be used for moving small loads such as drums, etc., and is operated by tilting the drum over slightly, inserting the blade between the floor and the bottom of the drum, and then tilting the drum back on the platform so that the load is then transported at approximately a 45 degree angle to the floor.



Courtesy of Link-Belt Co.

FIG. 38. CUT-AWAY VIEW OF A TYPICAL SCREW CONVEYOR

(7) ***Transporters.***—Transporters are small lift trucks. They come equipped with either a high or low lift and are either manual or powered in operation. They are used for short movements of material on skids or pallets. They are of particular benefit in unloading truck and rail car shipments from the car or truck to the receiving platform. They can be furnished with only their travel powered or with both the lift operation and the travel powered. The power source is an electric storage battery.

(8) ***Fork Trucks.***—The fork truck is used in warehouse operations for the handling of heavy loads. These trucks have varying heights of lifts that enable the operator to stack palletized loads, one on top of the other. They have speeds of travel in excess of a man's normal walking rate. Fork trucks may be classified as to power source as follows, (a) battery-electric, where the storage battery supplies the energy for electric control and power transmission, (b) gas-electric, where the power source is a gas engine generator, and (c) gas-mechanical, where the power source is a gasoline engine.

(9) ***Special Bulk Containers.***—In the evolution of developing means to ship granular ingredients in bulk, several methods were devised wherein containers having a capacity of approximately 4,000 lbs. were loaded at the mills or refineries, hermetically sealed, and shipped by rail car or truck to the bakery involved. One such container consisted of a completely enclosed aluminum bin with an opening on the top for filling and an opening on the side at the bottom of the bin for discharging. This bin was well insulated for warmth retention and proved to be satisfactory in certain types of applications. Other similar units were made of cardboard sides and top with a base similar to a wooden skid. Another

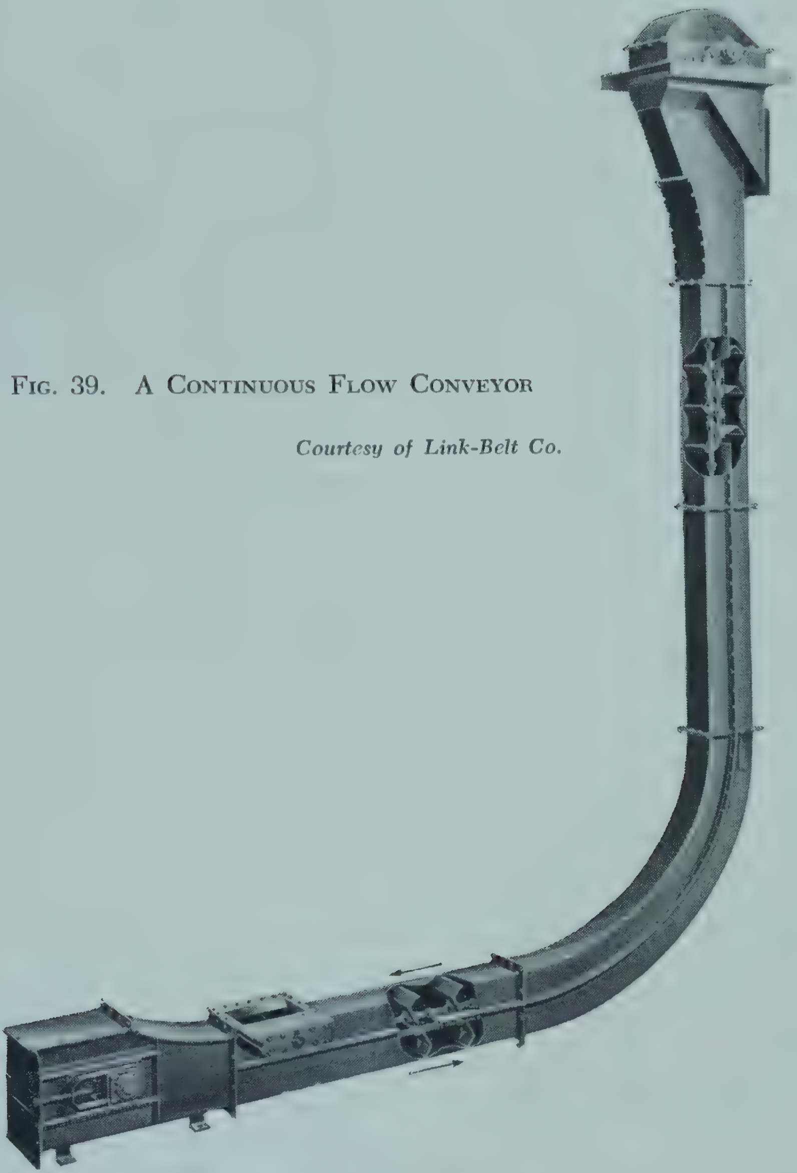


Fig. 39. A Continuous Flow Conveyor

Courtesy of Link-Belt Co.

unit that has been used successfully was made of rubber. The rubber container could be deflated for backhauling to the mill with a resultant saving in freight costs. In all cases, these special containers were moved about by means of a transporter or a fork lift truck.

(10) ***Conveyors.***—Conveyors used in transporting ingredients within a bakery can be classed as either mechanical or pneumatic in operation. The principal mechanical types used are (a) screw conveyors, and (b) continuous flow conveyors.

The *screw conveyor* (Fig. 38) usually consists of a long-pitch steel plate helix mounted on a shaft or spindle carried in bearings within a U-shaped trough. As the shafting rotates, the material fed to it is moved forward by the thrust of the lower part of the helix and is discharged through openings in the bottom of the trough or at the end. This type of conveyor is particularly suited for moving materials short distances on a horizontal line. Care should be taken that all parts of the rotating element and the interior of the housing be readily accessible for complete cleaning and that the housing be completely dust-tight.

The *continuous flow conveyor* (Fig. 39) is a machine in which the material moves slowly within a duct as a continuous core. An Englishman named Redler first devised this method of moving a flowable granular material by means of spaced flights attached to a steel cable. Conveyor manufacturers in this country have refined the original design, substituting chains for the cables.

This type of conveyor will self-load itself to capacity, cannot overload and does not require a feeder. It conveys material equally well vertically as horizontally. It is adaptable to a wide variety of granular materials and is a very economical means of conveying from a first cost standpoint.

A *pneumatic conveying system* differs entirely from other machines for transporting materials. It depends on an air stream to move granular materials. The movement of this air can transport material on either the suction side of the blower (called the exhauster in this application), or on the pressure side, depending on the particular design of the conveying system. Material is fed into the air stream by means of a feeder rotating at a predetermined rate.

The material is separated from the air at the point of discharge into the storage bins by centrifugal means or highly efficient filters, or both. A secondary reclaiming system is sometimes used to further recover material from the air discharged through vents at the tops of the tanks.

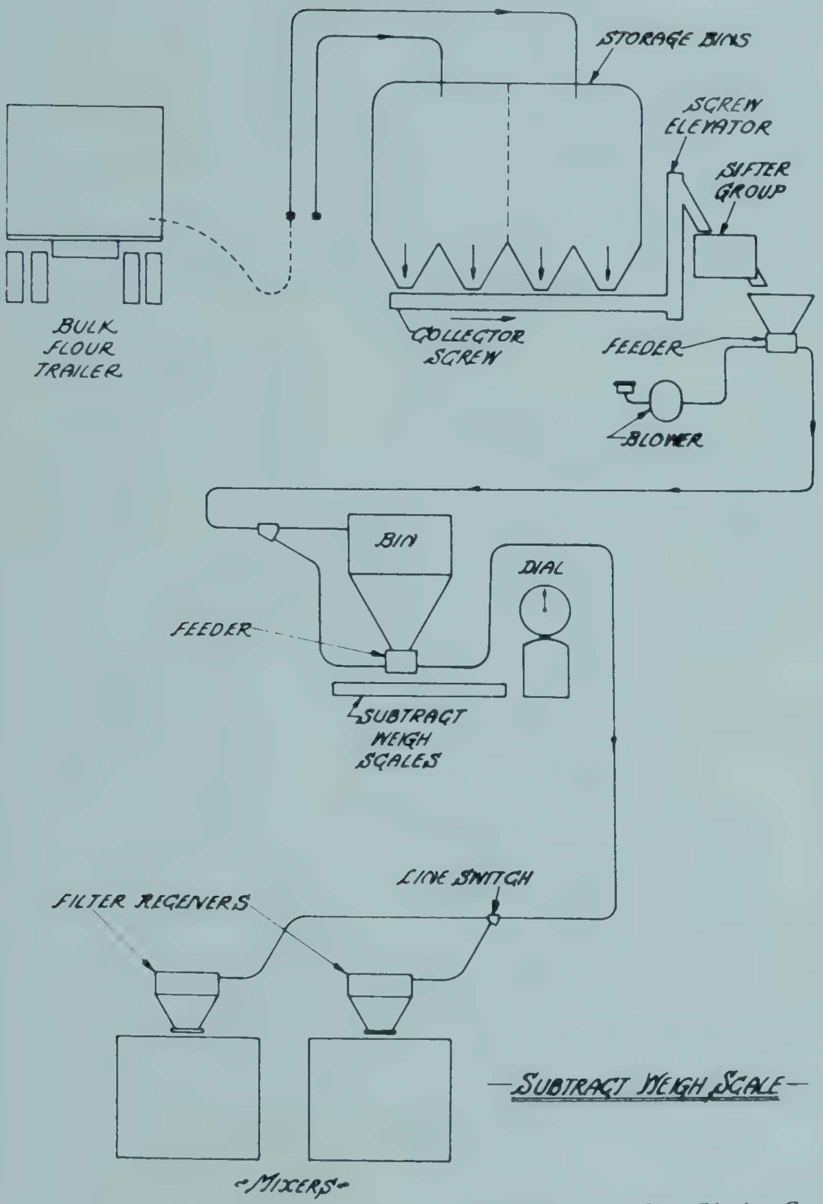
This type of conveyor has been used principally for the moving of flour and sugar within a bakery.

In some special installations where breakage of fragile granulated sugar crystals was undesirable, *apron type conveyors* have been used for horizontal movement.

Bulk Handling of Flour.—A complete bulk flour handling system can be separated into several component groups. Each grouping of machine units includes a beginning and end of flour conveyance. The ten operations listed below, when connected by conveying tubes will transport flour from the point of receiving to the point of use.

(1) Transportation of flour from mill to bakery by bulk truck or bulk railroad car.

(2) Unloading and conveying from car or truck by either vacuum or pressure leg of blower (or exhauster if vacuum leg is used).


STORAGE BINS
SCREW ELEVATOR
SIFTER GROUP
BULK FLOUR TRAILER
COLLECTOR SCREW
FEEDER
BLOWER
BIN
DIAL
FEEDER
SUBTRACT WEIGH SCALES
LINE SWITCH
FILTER RECEIVERS
—SUBTRACT WEIGH SCALE—
—MIXERS—

Courtesy of Fred D. Pfening Co.

FIG. 40. A TYPICAL ARRANGEMENT FOR UNLOADING BULK FLOUR TRAILERS, SHOWING A SCREW CONVEYOR UNDER THE STORAGE BINS

(3) Storage facilities within plant—either horizontal type bins or vertical silos.

(4) Conveying flour between storage tanks and sifter.

(5) Sifting operation and conveying from sifter to use bin.

(6) Hold in use, or service bin.

(7) Convey from feeder under use bin to scale hopper.

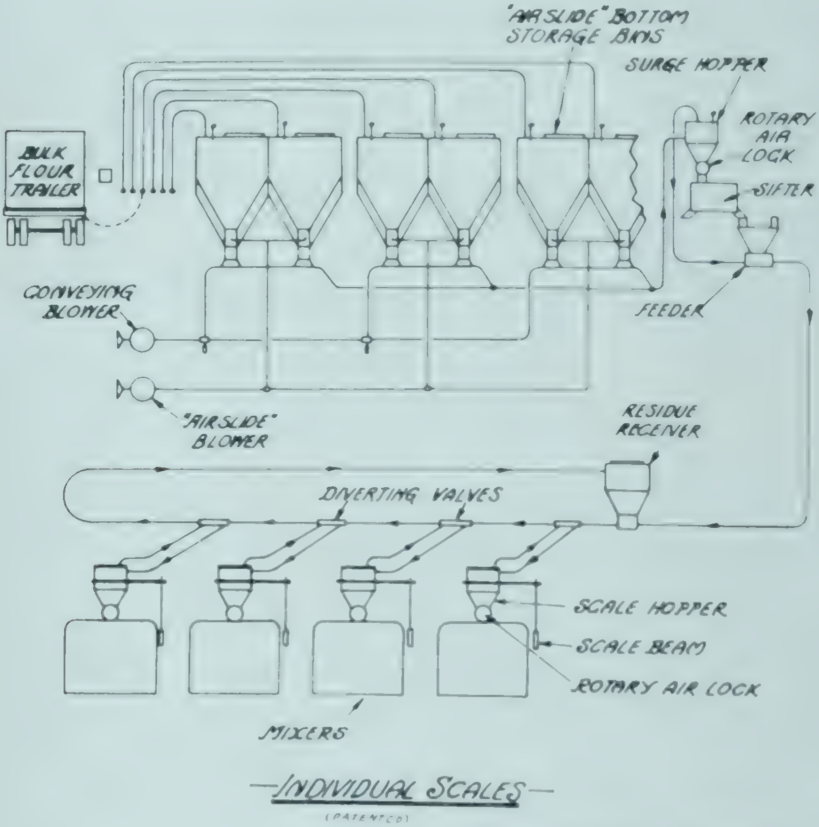
(8) Pass-through scaling operation. (Three scaling arrangements ar shown in Figs. 40, 41, and 42.)

(9) Convey to mixers.

(10) Disposing of used air at all transfer points.

(11) All of the above groups are timed and controlled by a complete overall electrical circuit which interlocks and sequences operations.

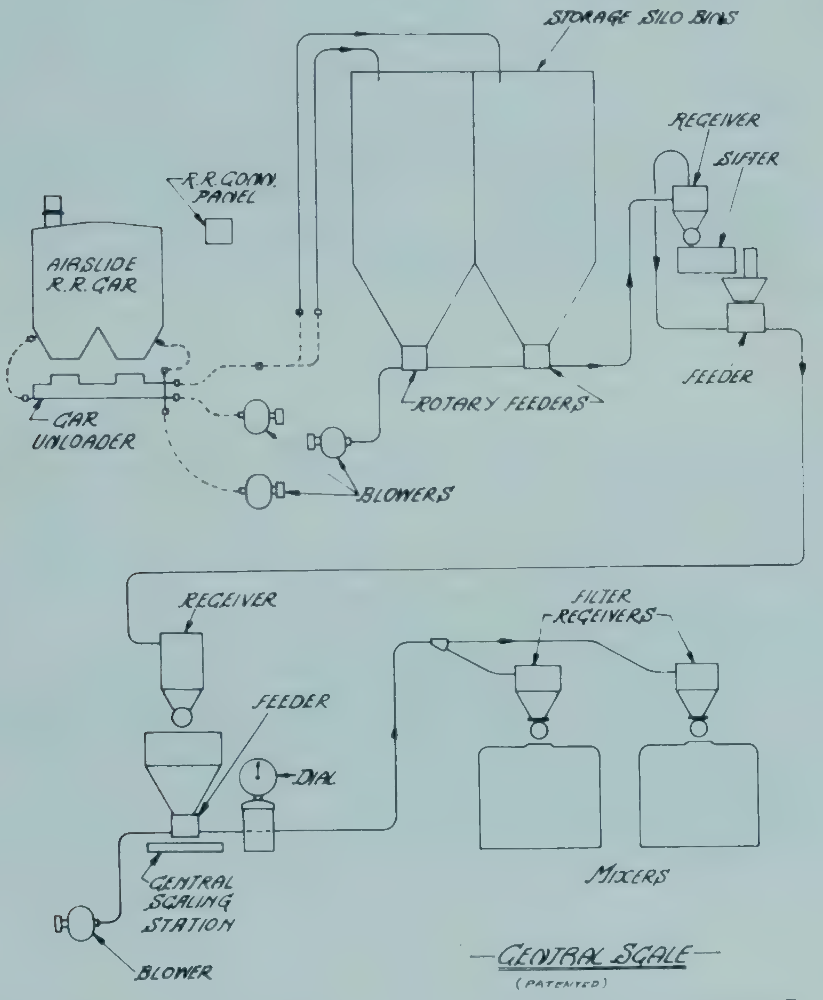
Special railway cars have been manufactured by General American Transportation Company for transporting flour and sugar in bulk. They are loaded by gravity through the roof hatches and can be unloaded by either a vacuum or pressure pneumatic handling system. The design of the bottom outlets is such that they can discharge into hoppers below the track or into any mechanical conveying system—permanent or retractable. The bottom of the compartments in the cars consist of two trenches running the full length of the car on each side of the center sill. Fastened to the underside of each trench is an Airslide which consists of sturdy, silicone-treated fabric one-quarter inch thick and twelve inches wide. The


"AIR SLIDE" BOTTOM STORAGE BINS
SURGE HOPPER
ROTARY AIR LOCK
SIFTER
BULK FLOUR TRAILER
CONVEYING BLOWER
FEEDER
"AIRSLIDE" BLOWER
RESIDUE RECEIVER
DIVERTING VALVES
SCALE HOPPER
SCALE BEAM
ROTARY AIR LOCK
MIXERS
—INDIVIDUAL SCALES—
(PATENTED)

Courtesy of Fred D. Pfening Co.

FIG. 41. TYPICAL ARRANGEMENT FOR UNLOADING BULK FLOUR TRAILERS, SHOWING INDIVIDUAL SCALES AT MIXERS

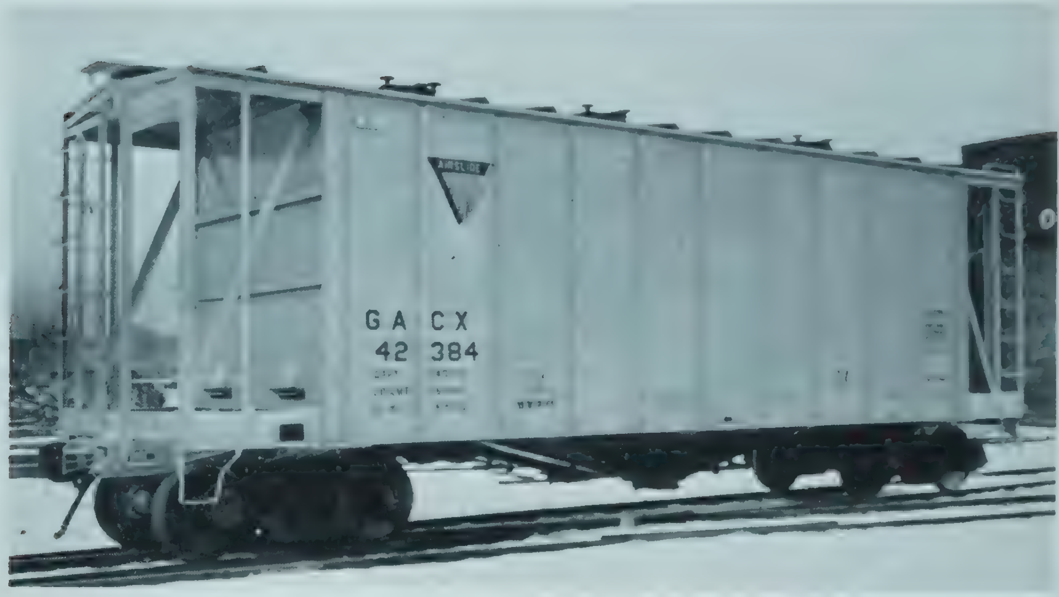
underside of the Airslide fabric is totally encased by a U-section of steel, which acts as a chamber to allow the low pressure air to completely permeate the Airslide fabric, thereby effecting aeration of the flour during unloading. This aeration effect causes the material to flow, by gravity, down the Airslide fabric, which slopes at an angle of approximately 15 degrees to the discharge outlets located at the center of the car.


STORAGE SILO BINS
RECEIVER
SIFTER
R.R. CONN. PANEL
AIRSLIDE R.R. CAR
FEEDER
CAR UNLOADER
ROTARY FEEDERS
BLOWERS
RECEIVER
FILTER RECEIVERS
FEEDER
DIAL
CENTRAL SCALING STATION
MIXERS
BLOWER
—CENTRAL SCALE—
(PATENTED)

Courtesy of Fred D. Pfening Co.

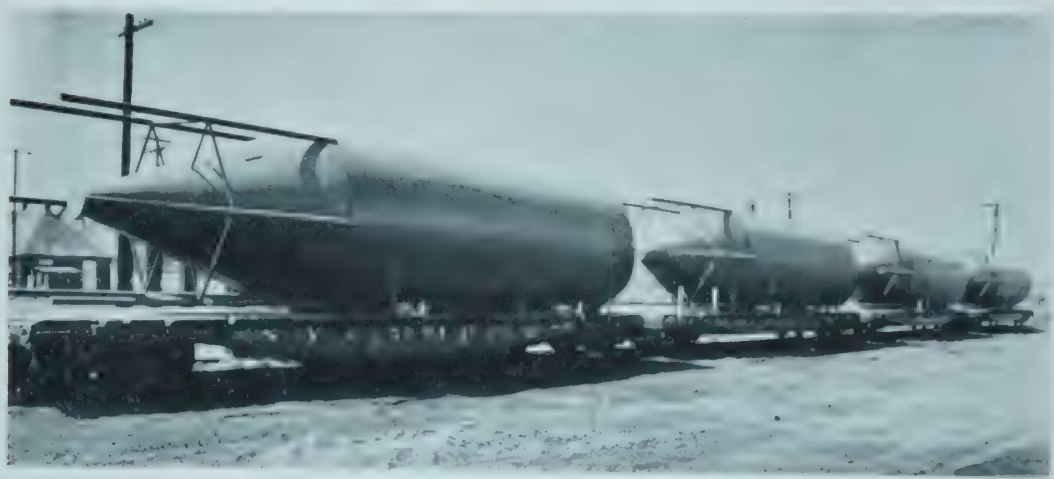
FIG. 42. ARRANGEMENT FOR UNLOADING RAILROAD CARS, SHOWING A SYSTEM WITH CENTRAL-SCALING

In the design of the Airslide car (Fig. 43), the following features are embodied in an effort to reduce to a minimum the amount of material retained after unloading: (1) all welded construction is used throughout the body; (2) the slope sheets make an angle of 60 degrees with the horizontal providing maximum slope with resultant minimum product



Courtesy of General American Transportation Co

FIG. 43. THE "AIRSLIDE" RAILROAD CAR



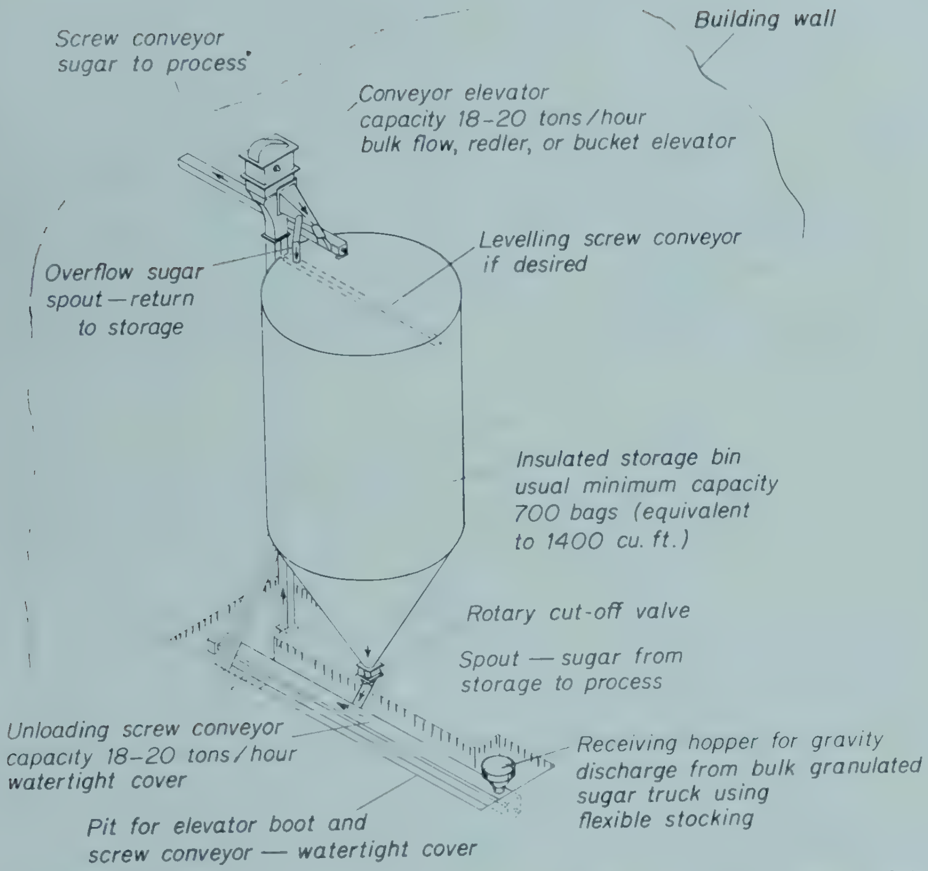
Courtesy of Fred D. Pfening Co

FIG. 44. TYPICAL SILO-TYPE STORAGE BINS EN ROUTE TO A BAKERY

retention; and (3) structural members and protuberances have been placed on exterior of car to provide for a smooth, interior surface.

Fig. 44 shows typical silo type storage bins enroute to a bakery for installation. Another widely used type of bin is of horizontal type construction and is sometimes required when headroom is a problem.

Storage tanks are unloaded by means of pneumatic conveyors, screw-type conveyors, and continuous flow-type conveyors. Oftentimes the horizontal type of bin will be equipped with Airslide bottoms in the same way as the bulk railroad car.


Screw conveyor sugar to process
Building wall
Conveyor elevator capacity 18-20 tons/hour bulk flow, redler, or bucket elevator
Levelling screw conveyor if desired
Overflow sugar spout—return to storage
Insulated storage bin usual minimum capacity 700 bags (equivalent to 1400 cu. ft.)
Rotary cut-off valve
Spout — sugar from storage to process
Unloading screw conveyor capacity 18–20 tons/hour watertight cover
Receiving hopper for gravity discharge from bulk granulated sugar truck using flexible stocking
Pit for elevator boot and screw conveyor — watertight cover

Courtesy of C. and H. Sugar Refining Co.

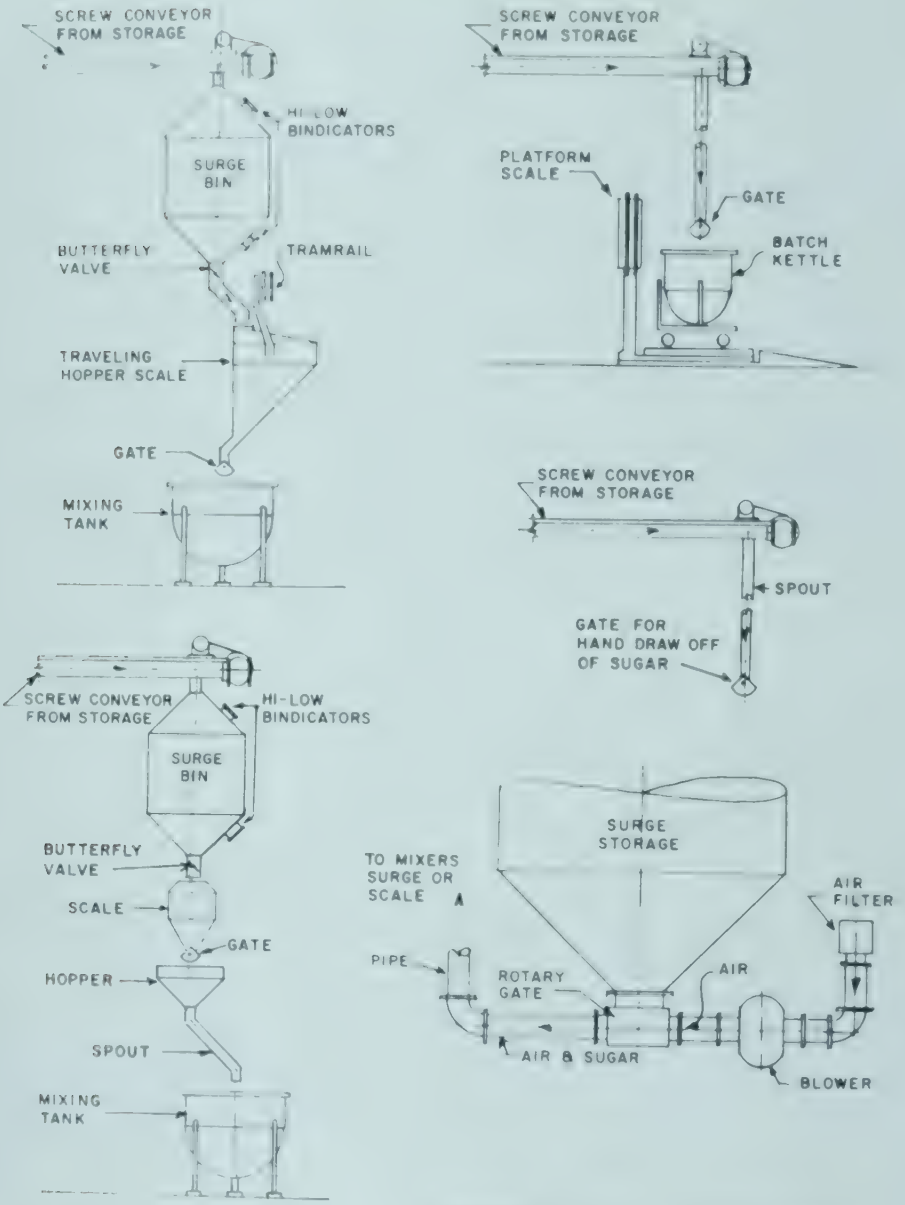
FIG. 45. A BULK GRANULATED SUGAR STORAGE INSTALLATION ADAPTABLE TO EITHER RAIL OR TRUCK DELIVERIES

Bulk flour trailers are available with either the Airslide bottoms or screw conveyor unloading. They are also usually equipped with a blower unit so that the material can be pumped directly into the users' storage bins.

There are several types of blowers available in several different sizes. At this point it should be stated that for satisfactory operation of a system insuring sufficient volume of air, pressure and velocity in proportion to the length and diameter of the conveying tube, care should be taken in making all calculations.

Bulk Granulated Sugar Storage Installation.—The same rail and truck transportation used for flour can also be used for bulk sugar. At the point of unloading either mechanical or pneumatic conveyors can be used.

Fig. 45 shows a typical bulk sugar storage arrangement. Both the screw-type conveyor and continuous flow-type conveyor are being used.


SCREW CONVEYOR FROM STORAGE
HI LOW BINDICATORS
SURGE BIN
BUTTERFLY VALVE
TRAMRAIL
TRAVELING HOPPER SCALE
GATE
MIXING TANK
SCREW CONVEYOR FROM STORAGE
PLATFORM SCALE
GATE
BATCH KETTLE
SCREW CONVEYOR FROM STORAGE
SPOUT
GATE FOR HAND DRAW OFF OF SUGAR
SCREW CONVEYOR FROM STORAGE
HI-LOW BINDICATORS
SURGE BIN
BUTTERFLY VALVE
SCALE
GATE
HOPPER
SPOUT
MIXING TANK
SURGE STORAGE
TO MIXERS SURGE OR SCALE
AIR FILTER
PIPE
ROTARY GATE
AIR
AIR & SUGAR
BLOWER

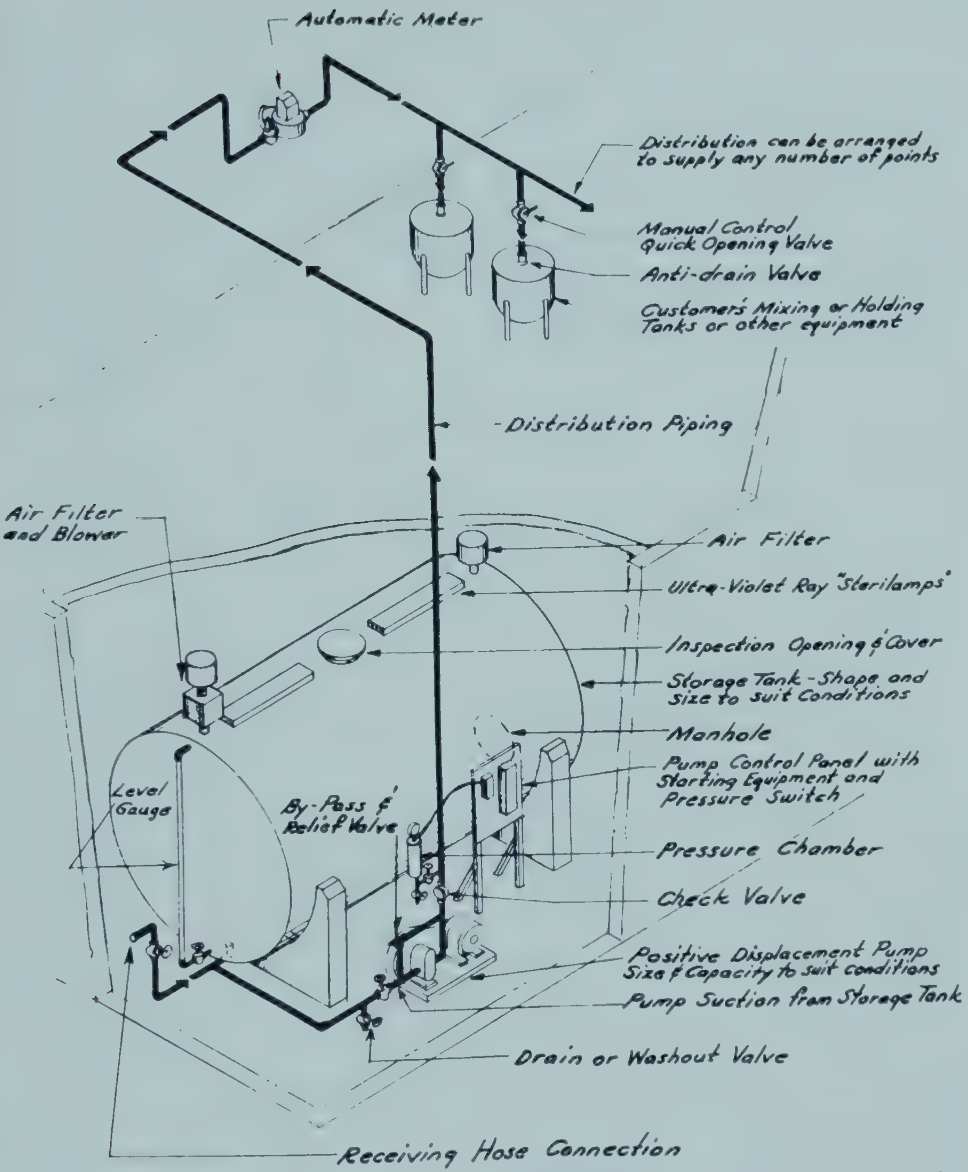
Courtesy of C. and H. Sugar Refining Co.

FIG. 46. BULK SUGAR IN-PLANT DISTRIBUTION SYSTEMS

Fig. 46 shows the delivery side of the conveyor line from storage. A screw conveyor is usually used for transporting sugar horizontally. It will be noted that a pneumatic system is indicated in the lower right hand illustration.

Corn sugar can be handled through a system similar to the one shown.

Handling of granulated sugars in bulk presents very few problems. Possibly the principal one is caking during humid weather. It is often desirable to recirculate the sugar through the closed conveyor system


Automatic Meter
Distribution can be arranged to supply any number of points
Manual Control Quick Opening Valve
Anti-drain Valve
Customer's Mixing or Holding Tanks or other equipment
Distribution Piping
Air Filter and Blower
Air Filter
Ultra-Violet Ray "Sterilamps"
Inspection Opening & Cover
Storage Tank - Shape and Size to suit Conditions
Manhole
Pump Control Panel with Starting Equipment and Pressure Switch
Level Gauge
By-Pass & Relief Valve
Pressure Chamber
Check Valve
Positive Displacement Pump Size & Capacity to suit conditions
Pump Suction from Storage Tank
Drain or Washout Valve
Receiving Hose Connection

Courtesy of C. and H. Sugar Refining Co.

FIG. 47. A LIQUID SUGAR STORAGE AND HANDLING INSTALLATION

periodically to break up the crust that forms on the surface if usage is not constant from the bin.

Bulk Handling of Liquid Cane and Beet Sugar.—Fig. 47 shows a typical liquid sugar storage and distribution installation. Liquid sugar installations in food manufacturing plants are all basically similar. The necessary equipment consists of storage tanks with accessories, pumps, metering or measuring equipment, and piping with various valves and fittings.

The first consideration in planning a liquid sugar installation is the storage facility. Factors to be considered are: Average usage, peak usage, proximity to source of supply, available space in the plant and cost of storage tanks.

The ideal is a two-tank system. Utilizing this type of system, each tank may be completely drained and liquid sugar is used on a "first in—first out" basis. Scheduling of orders is easier and cleaning of equipment is facilitated. If a two-tank system is decided upon, each tank should have a capacity of one load of liquid sugar. This would be determined by the size of equipment used for delivery. Truck loads usually are from 2,000 to 3,500 gallons. An air space approximately one foot in height should remain in the tank when filled. This precaution prevents liquid sugar from getting into accessories mounted on top of the tanks.

If it is not feasible to use two tanks, the single tank decided upon should have a capacity of one load plus 3 to 5 days supply. This would be determined by the servicing facilities offered.

Gauges for measuring inventory in tanks are of two types. One type provides a pipe fitting near the top of the tank and one near the bottom, for installing a gage to determine liquid level. The gauge consists of a clear, unbreakable plastic tube. It is attached by valves which are screwed to pipe fittings welded in the tank wall. The bottom valve must provide a means for draining the gauge. The other type is a float-operated gauge, with a dial mounted at eye level on the side of the tank.

Pumps used are of the rotary, positive displacement type. Process pumps normally are controlled automatically. A strainer having a removable bronze screen or perforated bronze basket is installed as a protection ahead of the pump. Usually a pump is provided on liquid sugar delivery equipment for unloading. In some cases, however, it is necessary to provide a second pump for this purpose.

Meters are of the positive volumetric displacement type. Each cycle of the piston in the meter measures and discharges a definite volume of liquid. An extremely accurate measurement results, which may be recorded in pounds of sugar or in gallons of liquid. Quantities are set by push buttons, and a cumulative totalizer provides an accurate record. An automatic stop as an accessory on the meter shuts off the flow when the desired amount of liquid sugar has passed through the meter, and makes the system automatic. The system may also be operated manually.

Piping may be of stainless steel, copper or galvanized iron. Galvanized pipe is by far the most commonly used, as it is less expensive. Screwed fittings are used in most installations. Quick-action gate or butterfly-type valves are preferred. Pipe thread compounds and valve packing and lubricants must be non-toxic and approved for use in the food industry.

Flow rate required and length of piping determine pipe size as well as pump size.

Piping must be installed to provide complete drainage of the system for cleaning. The entire piping system normally is kept full of liquid sugar.

Bulk Lard and Shortening.—This material is received in bulk in special railroad tank cars or in tank trucks. If the latter is used, they should be of the type used to transport fluid milk. The tank cars are usually equipped with steam heating coils to liquefy the material for unloading. These cars normally hold 60,000 lbs. of shortening. Tank trucks usually have a capacity of 30,000 lbs.

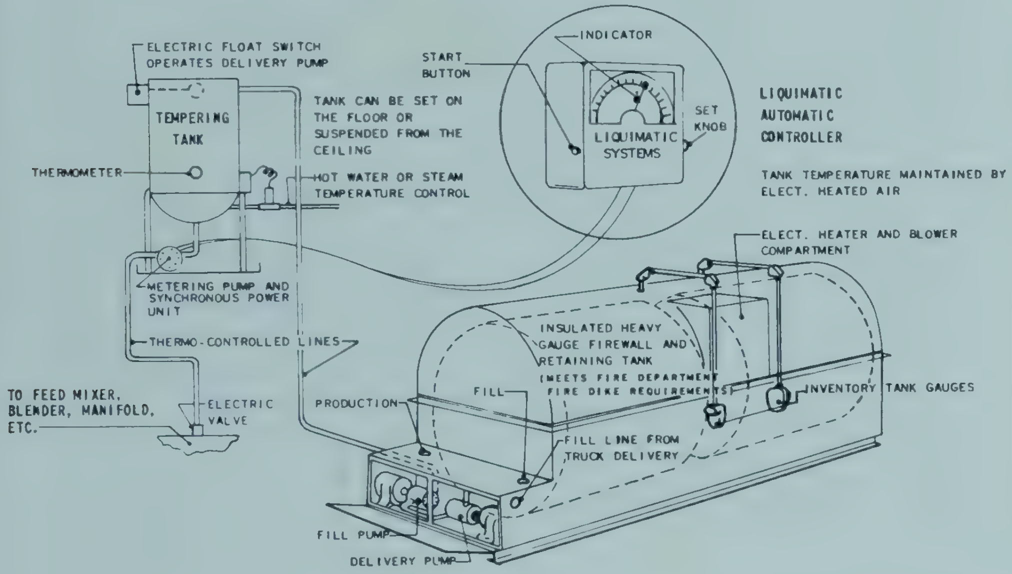

ELECTRIC FLOAT SWITCH OPERATES DELIVERY PUMP
TEMPERING TANK
THERMOMETER
TANK CAN BE SET ON THE FLOOR OR SUSPENDED FROM THE CEILING
HOT WATER OR STEAM TEMPERATURE CONTROL
METERING PUMP AND SYNCHRONOUS POWER UNIT
THERMO-CONTROLLED LINES
TO FEED MIXER, BLENDER, MANIFOLD, ETC.
ELECTRIC VALVE
START BUTTON
INDICATOR
LIQUIMATIC SYSTEMS
SET KNOB
LIQUIMATIC AUTOMATIC CONTROLLER
TANK TEMPERATURE MAINTAINED BY ELECT. HEATED AIR
ELECT. HEATER AND BLOWER COMPARTMENT
INSULATED HEAVY GAUGE FIREWALL AND RETAINING TANK (MEETS FIRE DEPARTMENT FIRE DIKE REQUIREMENTS)
INVENTORY TANK GAUGES
PRODUCTION
FILL
FILL LINE FROM TRUCK DELIVERY
FILL PUMP
DELIVERY PUMP

Fig. 48. A Bulk Handling Installation for Lard and Shortening

Liquimatic systems, self-contained portable package unit and metering system for hydrolized animal fat

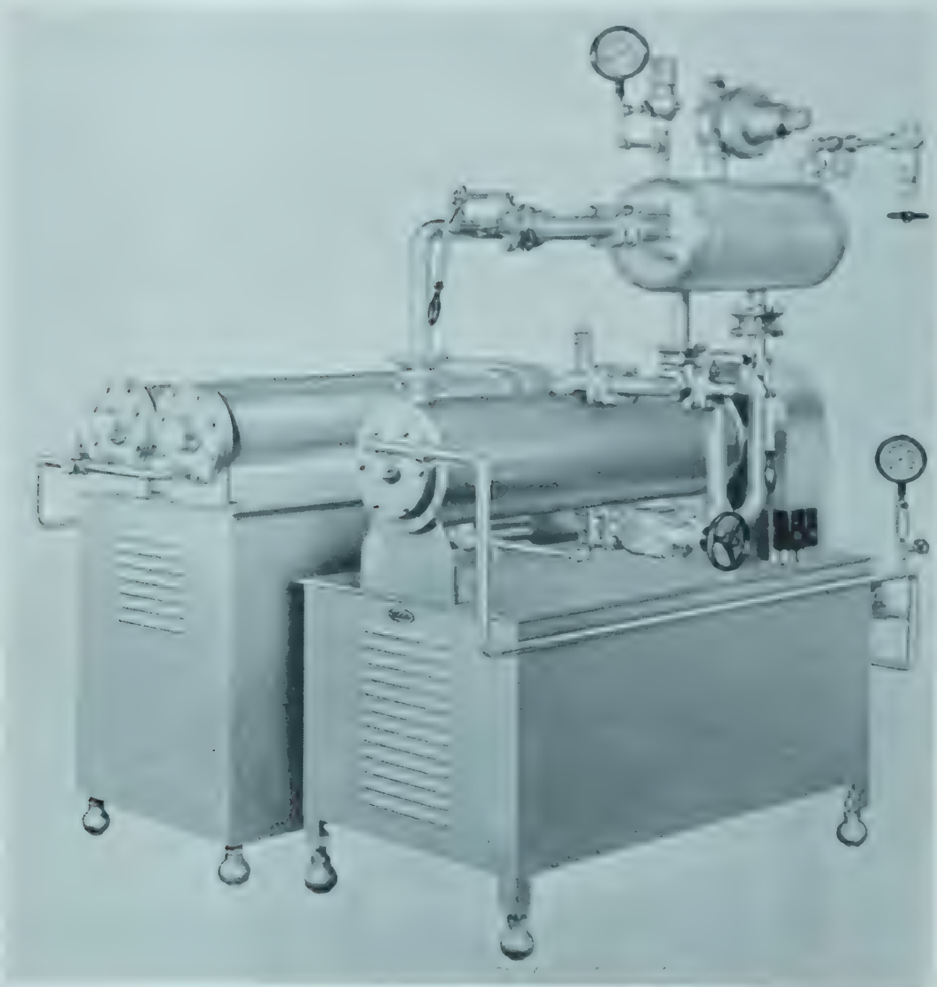
Positive displacement type pumps are used for pumping shortening.

Shortening manufacturers found long ago that copper, brass and monel metal, in fact, anything containing copper must not be permitted to come in contact with fats since even extremely minute quantities of this element greatly accelerate the development of rancidity in fats.

All valves should be of the gate type. It is usually advisable to trace all pumping lines with small diameter steam pipe or with electrically heated cables. In either case, insulation of the pair of lines will be necessary.

A typical bulk shortening handling installation is shown in Fig. 48.

Some plants have started to plasticize shortening which they buy in



Courtesy of Girdler Process Equipment Div.

FIG. 49. VOTATOR. A MACHINE USED FOR PLASTICIZING SHORTENINGS

the form of oil. Fig. 49 shows a Votator which is used to convert the oil into a plasticized state which, after a period of tempering, can be used for high quality production.

In handling some types of shortening, mechanical agitation should be provided in the storage tanks to prevent stratification of the oils. It is advisable to keep the entire system filled at all times to prevent condensation and oxidation.

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CHAPTER 14

John A. Abbott

Weighing and Mixing Procedures

INTRODUCTION

After the baker decides what weight of each ingredient to use in a product, he must measure out the ingredients, get them all into the same container and mix them together. Within the memory of a few people in the industry, bakers did this entire operation by hand, with simple measuring equipment dating back thousands of years in principle.

The need to reduce labor costs and to improve product uniformity led several years ago to the mechanization of the mixing operation in wholesale bakery practice. Through mechanization, productivity was raised until labor costs of the operation through the mixing stage comprised an extremely small part of the over-all cost of production.

With 2 or 3 bakery equipment manufacturers dominating the field, and offering similar equipment, the bread dough mixing process was rigidly standardized for many years. A generation of bakers completed trade schools and served out its time in the trade, believing implicitly that the bread making process in use was dictated by some immutable physical law.

In more recent years the curiosity and ingenuity of technically trained people close to the baking business have resulted in innovations in process equipment that have further reduced costs, and yielded products with characteristics different from the long accepted standards. The differences have been accepted as improvements in many cases and the new, automatic equipment has been installed as often for the desirable change in product as for the economies in production.

It is with current practices and equipment that this chapter on weighing and mixing is concerned. It is assumed that the formulas are known, and have been properly adjusted for the moisture content of the flour and the fermentation and bake-out losses, and that the ingredients are available and ready for use.

WEIGHING AND MEASURING DEVICES AND TECHNIQUES

Batch-Type Weighing and Measuring Equipment

Manual Scales.—In most bakery operations, wholesale as well as retail, the minor ingredients for each batch of dough or batter are weighed out

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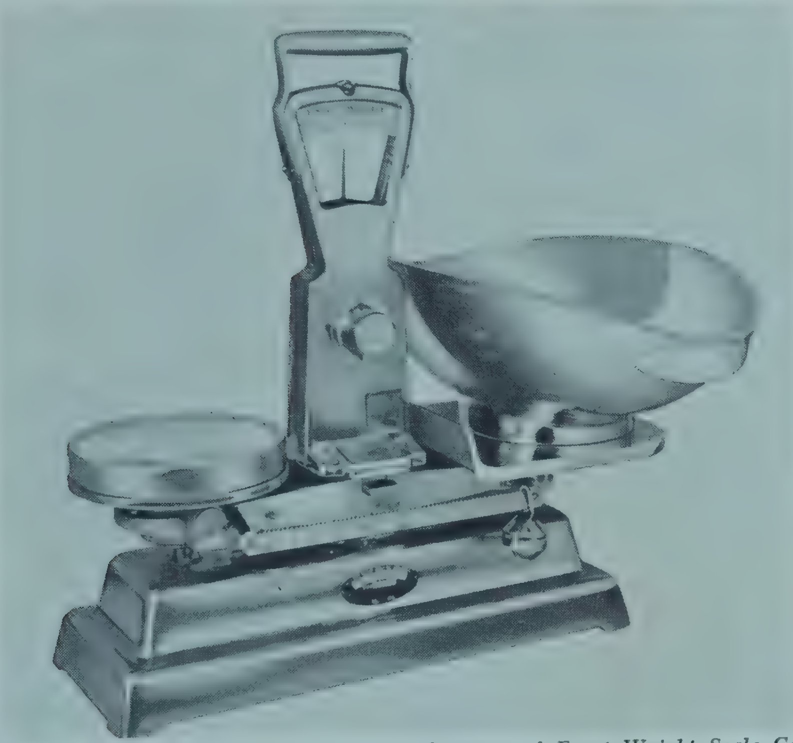
JOHN A. ABBOTT is New Products Director, Central Engineering Laboratories, Food Machinery and Chemical Corp.

by hand. The scaling operator starts work before the mixing operation begins, scales several batches in advance, and stays ahead of the mixer throughout the operating day. The weighed ingredient portions for each batch are kept together in stock pots or other suitable containers, on racks, dollies, or pallets, until used by the mixer operator.



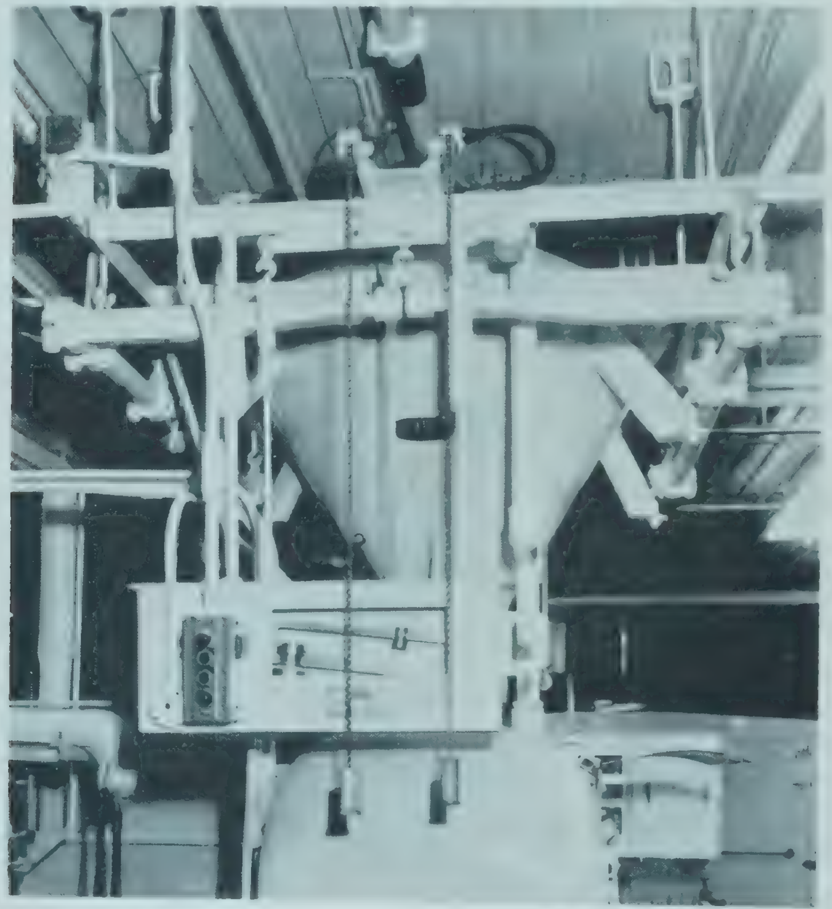
Courtesy of Exact Weight Scale Co.

Fig. 50. Small Scale for Bakery Ingredients

Equipment for weighing minor ingredients is simple in principle, but the design has been steadily refined to give maximum accuracy, durability, and ease of operation. Excellent bench scales to fill almost any conceivable need are available from several manufacturers. They are frequently of the beam-and-poise, even-balance type with over and under scale calibrations as shown in Fig. 50. Some models indicate accurate weights in the out-of-balance position.

To use a scale of this type the operator places a receiving container ("foot-scoop") on the platform and counterbalances this with an equal tare weight on the weight platter. He then sets the desired ingredient weight by placing weights on the weight platter and positioning the poise. The ingredient is poured into the foot-scoop until the pointer reads zero on the even-balance scale. The correct weight of ingredient is then discharged to a container.

Evolutionary progress in design has resulted in quick damping action and low platform deflection to allow fast reading. The accuracy of these commercial scale units is considerably better than that required for scaling bakery ingredients, and with typical scale graduations an operator can weigh out ingredients to plus-or-minus one-fifth of one per cent accuracy at a very high rate.



Courtesy of Read Standard Div.

FIG. 51. BATCH WEIGH HOPPER FOR FLOUR

For scaling ingredient batches up to 150 or 200 lbs., large bench scales are available in both the even-balance, and indicating-dial type. Shortening for a 1600-lb. batch of dough, for instance, would require a large bench scale of this type. The indicating-dial type scales may be equipped with a hand-set automatic stop pointer on the dial.

Major dry ingredients—flour for bread and flour and sugar for cake—can of course be weighed out by hand methods on a large bench scale but this is impractical in a wholesale bakery, where the flour for a large batch of bread dough may occupy a volume of 15 or 20 cubic feet.

Handling this volume every 15 minutes requires conveying equipment and some degree of automation in weighing techniques.

Automatic Scales.—The most common method of weighing flour in wholesale bakeries is with a weigh-hopper mounted on a beam scale directly above the mixer as in Fig. 51. Flour is conveyed from a sack dump bin or daily use bin, into the weigh-hopper. When the hopper contains the weight of flour previously set on the scale beam, the beam rises, actuates a mercury switch, and stops the conveyor. The scale must be adjusted to compensate for conveyor over-run to give an adequately accurate weighing. The operator discharges the hopper directly to the mixer at the proper time.

It has long been the practice in many weigh-hopper installations of this type to charge two or more mixers from one weigh-hopper, mounted portably on a structural steel track above the mixers. The hopper is moved to a position directly over the mixer to be next charged. However, as screw and bucket-elevator flour conveying systems have been replaced by pneumatic conveying equipment, necessitating permanent connections to the hopper, it has become more common to mount a weigh-hopper over each mixer.

In an alternative arrangement, economical where three or more mixers are used, a single weigh-hopper may be remotely located, and connected with the mixers it serves by pneumatic conveyor equipment and a suitable switching arrangement. The patented Pfening Central Scaling System is an example. A scaling-room located hopper may be operated by the scaler and actuated by signal from the mixer operator, even though the hopper is located 2 or 3 floors below the mixing room.

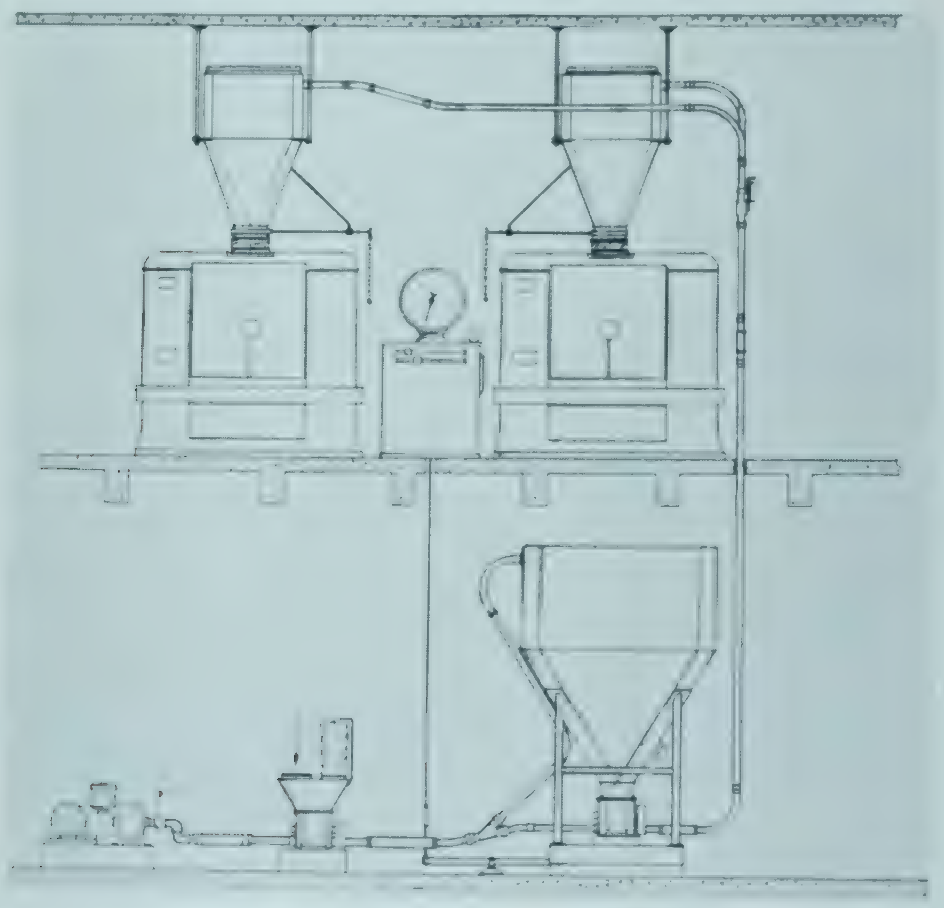
In a mixing operation in which the mixing bowls move in and out of the mixer—as with the large cake mixers for 500-lb. batches of batter—it is common to mount weigh-hoppers for flour and sugar in a convenient location, and position the portable dolly-mounted bowls under the hopper discharge chutes for filling.

Automatic cut-off, dustless type weigh-hoppers are available from several manufacturers. Sizes vary from 150 to 1500 lbs. of flour by increments of 50 lbs. in the smaller sizes, and 200 or 300 lbs. in the largest sizes. The baker provides the structural steel framework supporting the hopper system.

An alternate arrangement to the use of weigh-hoppers is "subtract-weight" scaling. In an early embodiment of this principle a small flour dump bin and overhead conveyor delivery system were mounted on a large scale-platform, with delivery system arranged to discharge directly to the mixer. The control system was arranged so that the desired net weight of flour could be set with a dial and pointer and the conveyor actuated with a pushbutton. When the system had discharged the preset weight of flour, a mercury type switch shut off the conveyor.

In the Pfening "subtract-weigh" system this principle has been developed into an efficient system using pneumatic conveying.

In a typical installation a 5000-lb. use-bin can be mounted on a subtract-weigh platform, in the flor storage room, with flour batching controls and scale head mounted near the mixers. A remotely operated scale head may be used if the sealing platform is not in a direct line with the desired scale head location, as it is in Fig. 52.



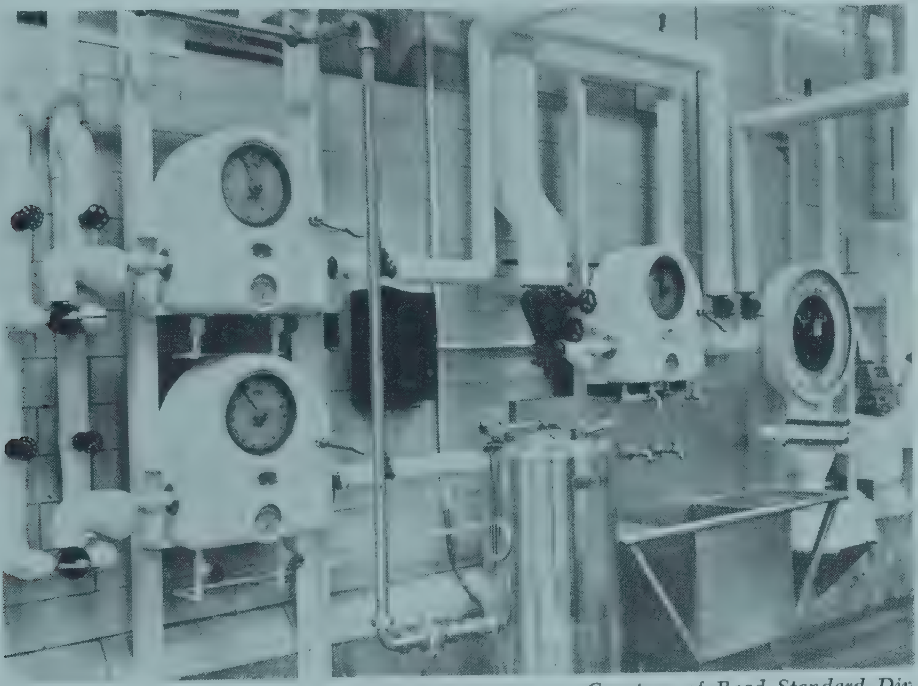
Courtesy of Fred D. Pfening Co.

FIG. 52. CENTRAL SUBTRACT-WEIGH SCALE WITH REMOTE DIAL SERVICING TWO DOUGH MIXERS

With this method of flour scaling, weighing inaccuracies due to conveyor line hold-up are prevented by arrangement of the valving. The feeder shuts off immediately as soon as the amount of flour that is selected *leaves the storage bin.* The weighed flour that is in the pneumatic tubing at shut-off is purged into the holding hopper over the mixers, so the lines are always clear.

Flour delivery rate with this system may be varied from 200 to 700 lbs. per minute. Thus the holding hoppers above several mixers may be kept charged according to the mixing schedule.

Volumetric Measuring Devices.—The foregoing discussion was concerned with apportioning of ingredients by weighing, the only way to measure accurately a material of variable bulk density, like flour. Granted it is practical to batch flour to a mixer by number of sacks, but it was first necessary to weigh the flour into the sacks at the mill. Likewise, eggs for the wholesale cake mixing operation are generally measured by number of commercial 30-lb. cans. Sometimes the basis of the batch is a whole number of egg cans, rather than 100 lbs. of flour. This system obviously depends on accurate weight scaling and quality control by the egg packer.



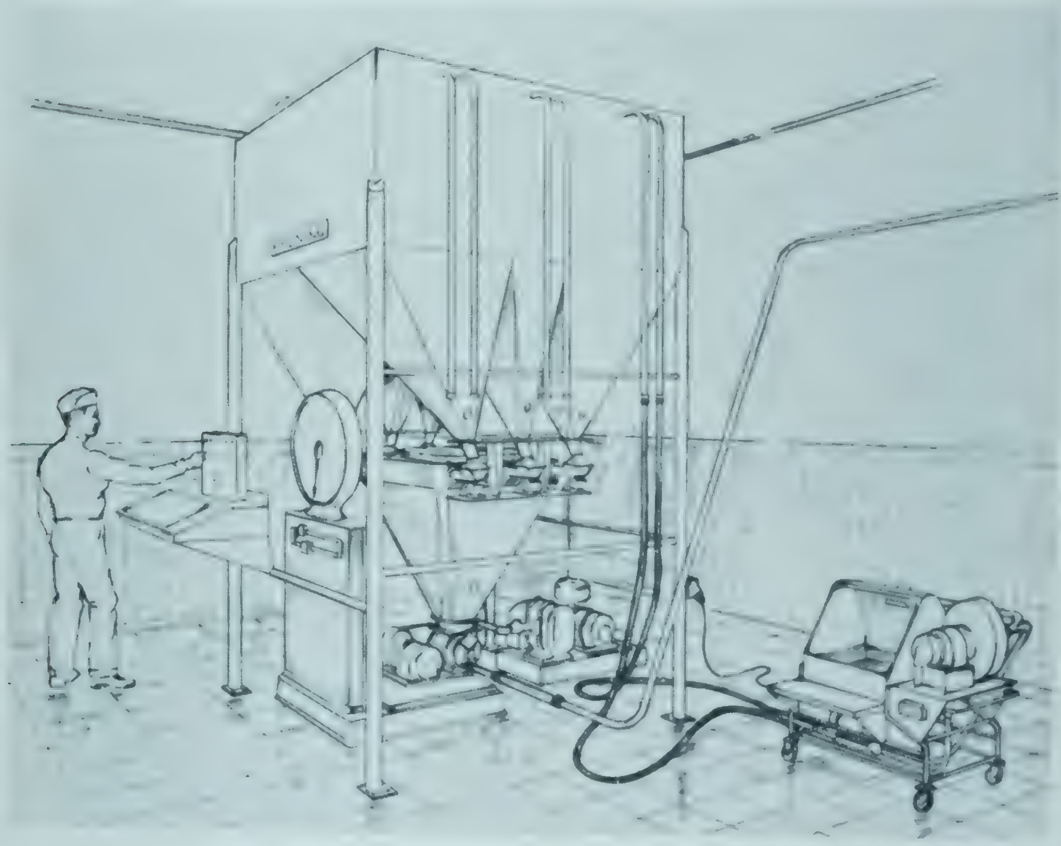
Courtesy of Read Standard Div.

FIG. 53. AUTOMATIC LIQUID BATCHING SYSTEM

Some ingredients, such as water and liquid sugar, because they are of relatively constant specific gravity and per cent concentration, may be measured with sufficient accuracy by volume.

Commercial equipment for liquid batching is designed and built around a positive displacement hydraulic pressure operated, rotary volume meter as shown in Fig. 53. The basic meter unit is geared to an indicator which is hand-set for the desired weight of water. The inlet valve closes automatically when the indicated weight of water has passed through the meter.

Water meters are connected frequently with both hot and cold water supplies through a mixing valve. By adjustment of the valving the operator can deliver to the mixer water of the desired intermediate temperature.



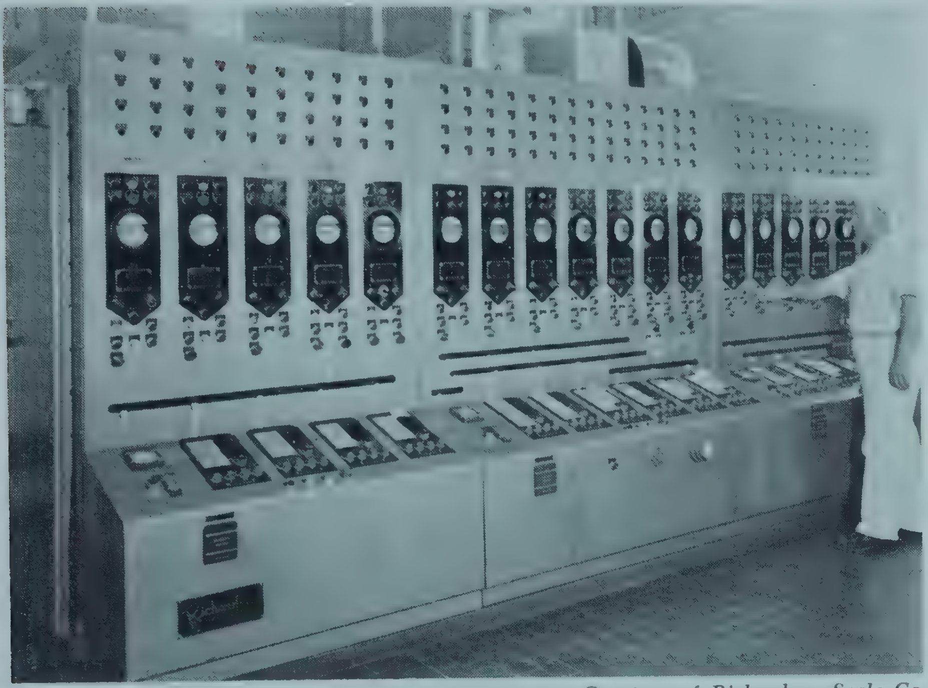
Courtesy of Fred D. Pfening Co.

FIG. 54. INGREDIENT SCALING STATION HANDLING SIX DRY INGREDIENTS

Obviously there is an inaccuracy inherent in this system due to variability of specific gravity with temperature. However, the difference in specific gravity of water at 68° F. from that at 86° F. is only one-fourth of one per cent. and this error, combined with that due to dimensional temperature changes in the metal parts of the meter, is quite insignificant. Manufacturers report accuracies at any point on the dial within ¾ to 1 per cent.

The advantages of this type of meter are unquestioned and its use is universal in the baking industry. Sanitary type rotary meters are available for metering premix brew, milk, etc.

Occasionally one sees a calibrated batch tank for apportioning water by volume, connected into the water supply line, but the automatic water meter has replaced most such equipment. Liquid shortening can be



Courtesy of Richardson Scale Co.

FIG. 55. CENTRAL CONTROL PANEL FOR INGREDIENT SCALING

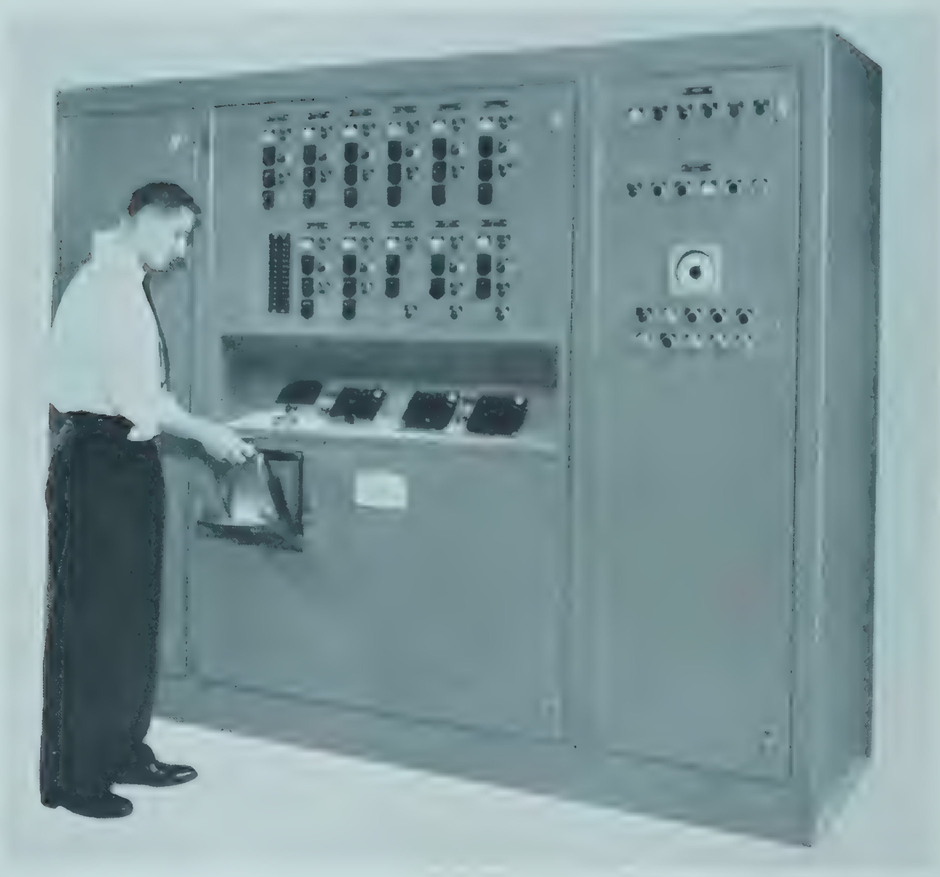
Installed by Richardson Scale Company in the Philadelphia bakery of the National Biscuit Company.

batch-metered conveniently by volume. Storage may be in the liquid form in large heated tanks, purged with inert gas, or in the plastic form in drums. In the latter case the drums are charged to a small steam or electrically heated melting tank, from which the shortening is metered and fed to the mixer. In either case the shortening is metered through a positive displacement pump, operated at constant speed for a definite, preset time interval depending on the quantity of shortening desired.

Integrated Automatic Batching Systems.—With the methods described in the preceding sections major ingredients are batch-metered automatically. The operator first registers the desired weight into the system by setting a dial or positioning a poise, then at the proper time pushes a button to have the desired weight of ingredient delivered to the holding tank, premixer, or mixer.

In some large bakery installations it is practical to handle small ingredients in this way. Automatic batch weighing and feeding equipment can be obtained to deliver small portions of dry milk solids, Arkady, etc. (Fig. 54).

The ability to batch-meter and deliver all ingredients automatically allows the entire scaling operation for a multiple-mixer bakery to be controlled from a central panel by one operator.



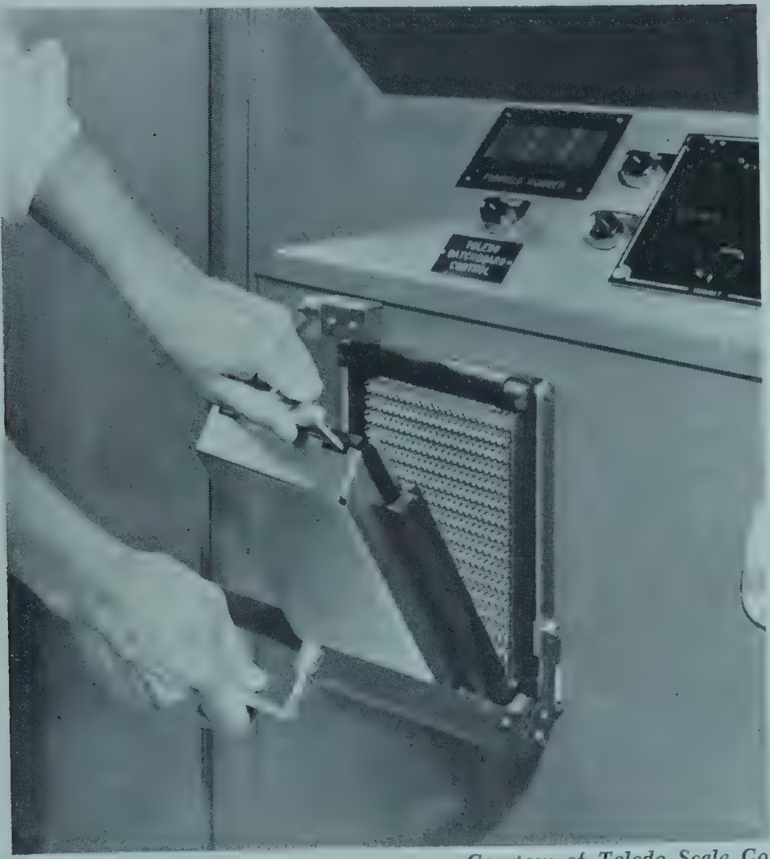
Courtesy of Toledo Scale Co.

FIG. 56. TOLEDO SCALE SYSTEM CONTROL PANEL WITH OPERATOR INSERTING "BATCHBOARD"

The central scaling control panel shown in Fig. 55 was installed by Richardson Scale Co. in the new Philadelphia plant of National Biscuit Co., with a complete ingredient batching system. This central panel is designed in three sections, each controlling the supply of 5 to 7 ingredients to 4 or 5 mixers. The operator has a mixer selector switch on each panel section, a dial to set the desired ingredient weight, and a button to deliver the ingredient to the proper mixer. Signal lights inform him when the ingredient has been delivered.

Programming of ingredient scaling in this case is done by the operator, but it is only a short step from this system to a fully automatic one wherein the programming is done by a punched card or perforated tape, on which the formula information is stored.

One new system embodying this principle has been put into commercial operation by the Toledo Scale Corporation. Instead of punched cards, "batchboards" are used to store formula information. The batchboard is actually a small portable switching device. An individual batch-



Courtesy of Toledo Scale Co.

FIG. 57. CLOSE-UP VIEW OF BATCHBOARD AND RECEPTACLE

board is set up for each formula in the bakery plant and when it is desired to run that formula the batchboard is inserted into the central control panel as shown in Fig. 56. A close-up of the batchboard is shown in Fig. 57.

Use of this system makes it practically impossible to mis-scale a formula. When the batchboard is inserted, the number of the formula is automatically displayed in a brilliant digital form on the central control panel.

If multiple batches of one batchboard formula are to be delivered, the operator selects the number of batches desired and feeds this number into the central control panel on the pre-set batch-counter.

This new equipment has sufficient flexibility to allow its use after proper installation in any wholesale bakery operation.

Semi-continuous and Continuous Measuring Devices

In the metering or proportioning of ingredients for batch mixers, the important factor is the *absolute quantity* of each ingredient delivered to the mixer—not the *rate* at which it is delivered. A continuous mixer, however, must receive a stream of all ingredients, each at the correct constant *rate* to give it the proper proportion in the finished mix. Continuous mixers must therefore be fed by continuous metering devices.

The water meters previously described, although they discharge the water in a continuous stream, are not continuous meters, but batching meters. The rate of water discharge is not constant but depends on pressure gradient across the metering system.

Continuous metering is rate metering, expressed in pounds per hour or pounds per minute. The product of the metering rate and operating time is the quantity metered.

The shortening meter consisting of constant speed pump and timing device is a rate meter. Operation for a given period delivers the definite quantity needed for the batch. The shortening meter could operate uninterruptedly to feed a continuous mixer, and it would then be functioning as a continuous meter.

In a continuous mixing system it is sometimes impractical to meter all the minor ingredient streams continuously, and several of them may be pre-combined, batchwise, into a larger stream for better metering with fewer pieces of equipment.

Continuous Solids Metering.—Dry solids such as flour may be satisfactorily measured in a continuous volumetric feeder, if the variation in bulk density of the solid is low enough to allow operation within the tolerable limits on scaling accuracy. One type of commercial volumetric feeder, the Omega Rotolock, has a horizontal cylindrical rotor with volumetric pockets, revolving beneath a gravity feed hopper. The rotor, turning at a preset constant speed, delivers a fairly constant volume of dry material from the pockets. Rate is varied by changing rotor speed, or, within wider limits, by changing rotors. The advantages of this type of feeder are moderate cost, rugged construction with reasonable metering accuracy (depending on the solid metered) and an extremely wide range of possible metering rates.

In another type of volumetric dry feeder, a horizontal circular disc rotates beneath a gravity feed hopper and carries a layer of dry solids under a gate. A spiral screed discharges the material from the disc. Gate height is variable to give a rate variation of 20 to 1. A much wider variation is possible by changing gears in the transmission driving the disc.

The advantages of this type of feeder are simple construction and lowest cost, coupled with fair accuracy (quoted ±3 per cent but this obviously depends on the characteristics of the solid).

For any new dry feeding application these volumetric devices should be evaluated to determine whether they provide sufficient accuracy, since they represent the least cost.

Unfortunately the major bread ingredient—flour—cannot be metered practically in this equipment in a commercial wholesale bakery. This is due to two important factors in addition to the limitations of the feeder.

First, the conditions under which flour is handled and conveyed in the bakery make it virtually impossible to hold a constant bulk density. Flour "fluffs" to various degrees, depending on its grind, blend, moisture content, and method of conveying. Moisture content varies with condition of storage. The flour undergoes a change in bulk density on standing in a hopper, particularly if it is vibrated.

Second, the absorption rate (ratio of water weight to flour weight) in the bread production process is critical, and a tolerance of ±1 per cent is desirable. (It should be noted that this close tolerance is not necessary *to make good bread,* but is necessary to insure sufficient uniformity of dough to allow efficient operation of make-up equipment.)

As a result, continuous flour metering systems can seldom make good use of the volumetric feeder. One important exception will be mentioned in the section on continuous mixing.

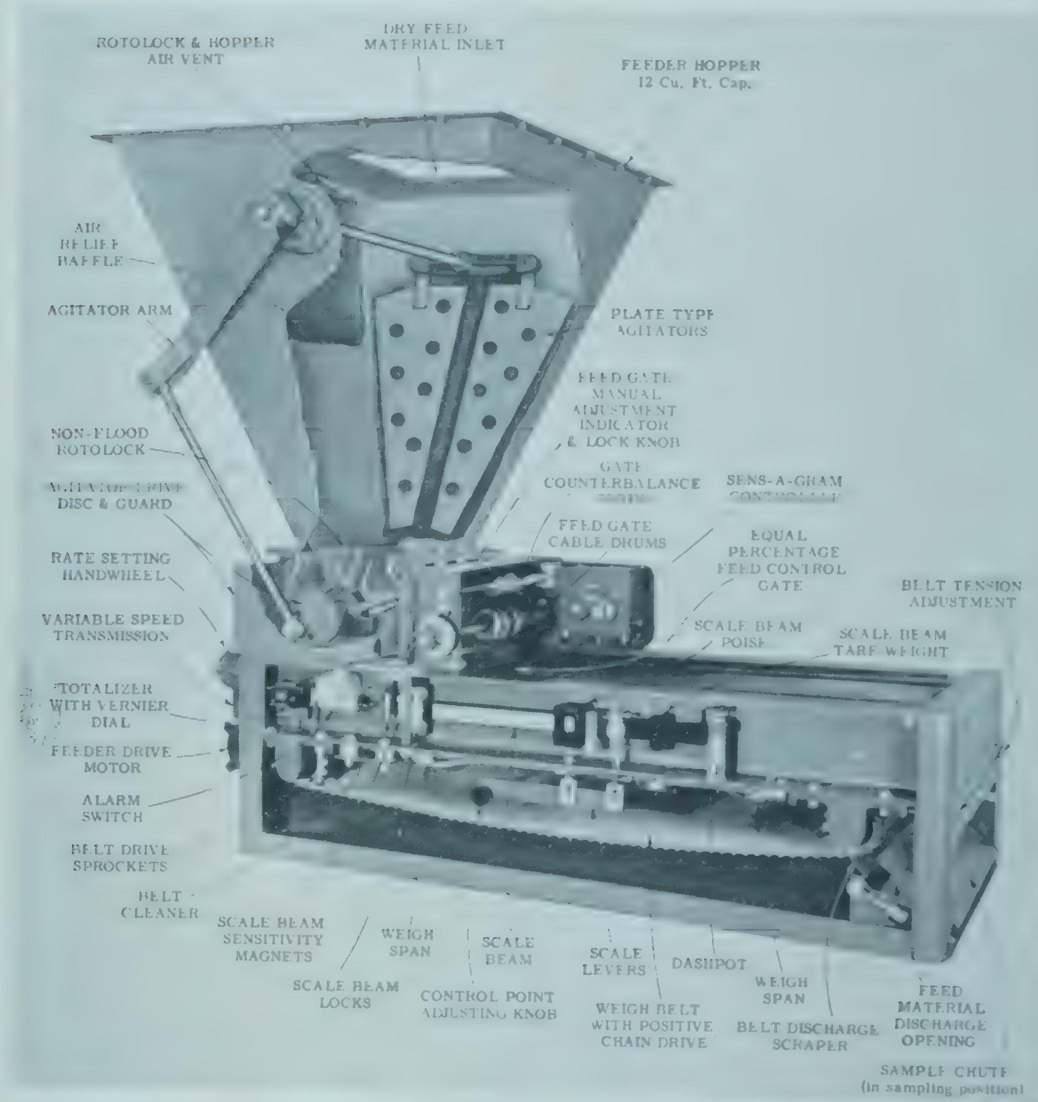
More accurate metering can be obtained for flour, sugar, etc., with the gravimetric belt feeder. A typical example is shown in Fig. 58. Machines of this general type are offered by two or more United States manufacturers. There are some differences in the operation of the different models, but the principles are similar.

A conveyor belt is mounted on a beam scale under a gravity feed hopper, and the net weight of the material on the belt and the speed of the belt determine the rate of feed. Typically, the belt speed and beam weight settings can be varied over a 100 to 1 range to vary feed rate. The thickness of the layer of dry solids on the belt is controlled by a vibrating hopper feed and rotary depositor, or by the height of a gate under which the material flows.

A mechanical or electrical feed-back controller adjusts the feed mechanism in accord with a signal from the beam scale, to keep the weight on the belt at the preset figure.

In a control system of this type there is a necessary delay in the feedback response, and abrupt changes in weight cannot be made by a change in scale beam setting. If the metering operation is such that frequent but small changes in feed rate are necessary, the changes can best be made, with no delay, by changing the belt speed, leaving the beam setting constant.

The guaranteed accuracy of commercial units is ±1 per cent of set feed rate over the entire operating range, when the sample is taken over


ROTOLOCK & HOPPER AIR VENT
DRY FEED MATERIAL INLET
FEEDER HOPPER 12 Cu. Ft. Cap.
AIR RELIEF BAFFLE
AGITATOR ARM
PLATE TYPE AGITATORS
FEED GATE MANUAL ADJUSTMENT INDICATOR & LOCK KNOB
NON-FLOOD ROTOLOCK
GATE COUNTERBALANCE SPRING
SENS-A-GRAM CONTROLLER
AGITATOR DRIVE DISC & GUARD
FEED GATE CABLE DRUMS
EQUAL PERCENTAGE FEED CONTROL GATE
RATE SETTING HANDWHEEL
BELT TENSION ADJUSTMENT
VARIABLE SPEED TRANSMISSION
SCALE BEAM POISE
SCALE BEAM TARE WEIGHT
TOTALIZER WITH VERNIER DIAL
FEEDER DRIVE MOTOR
ALARM SWITCH
BELT DRIVE SPROCKETS
BELT CLEANER
SCALE BEAM SENSITIVITY MAGNETS
WEIGH SPAN
SCALE BEAM
SCALE LEVERS
DASHPOT
SCALE BEAM LOCKS
CONTROL POINT ADJUSTING KNOB
WEIGH BELT WITH POSITIVE CHAIN DRIVE
WEIGH SPAN
BELT DISCHARGE SCRAPER
FEED MATERIAL DISCHARGE OPENING
SAMPLE CHUTE (in sampling position)

Courtesy of Omega Machine Co., Div. of B-I-F Industries

FIG. 58. CONTINUOUS WEIGHING FEEDER

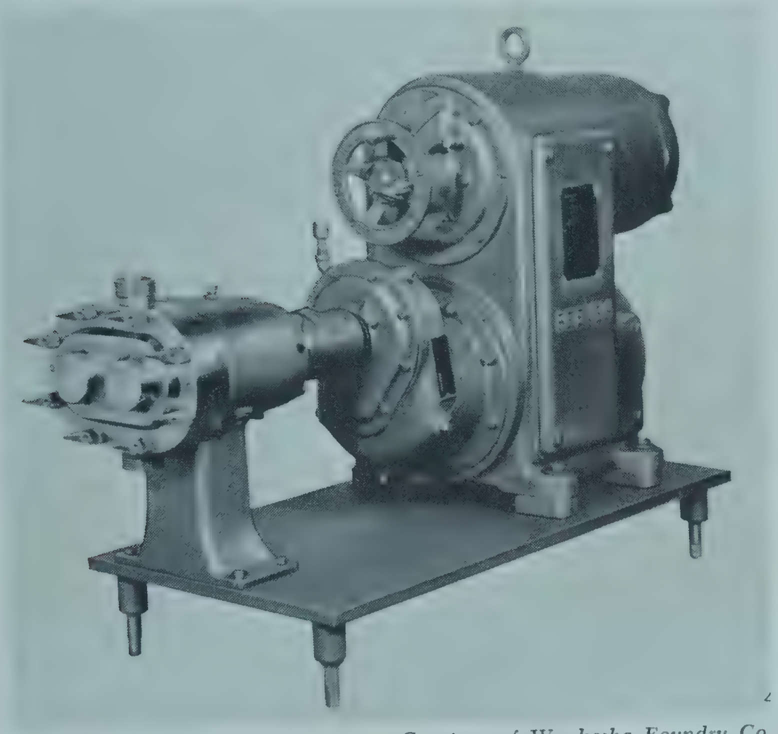
a two-minute period. The probable maximum error is less. In the continuous mixing systems using this equipment, the premixers and mixers have a residence time on the order of two minutes, therefore this accuracy is quite adequate for bakery mixing operations. Even though the instantaneous feed rate during a two-minute period may vary more than ±1 per cent, the variations are damped out in the accumulation of feed over the period.

Standard accessories for this equipment are feed quantity total indicators, rate indicators in per cent of maximum and variable speed transmissions.

The operating range of the commercially available gravimetric feeders is sufficient to supply flour to any of the new continuous bakery mixing systems.

There are other, more elaborate gravimetric feeding systems that could be used to feed bakery solids. One example is the Omega loss-in-weight system, which is not limited to feeding free-flowing pulverized solids such as flour, but will handle granular or lump material up to one inch in size. This more expensive system is not warranted for bakery use.

Continuous Fluid Metering.—Fluids metered into continuous mixing equipment include water, pumpable premix batches, shortening, and air. Volumes have been written on metering of fluids and there are countless varieties of equipment. Because bakery equipment must be sanitary, and preferably simple and rugged, only a few of the different devices are suitable for bakery use. Fortunately, the required metering accuracy in the bakery is only moderate, and elaborate sensing and feed-back control metering is unnecessary.



Courtesy of Waukesha Foundry Co.

FIG. 59. WAUKESHA LIQUID METERING PUMP

Pumps.—Positive displacement pumps can be used to meter liquids continuously under suitable conditions. If "sanitary" conditions do not prevail, and if pulsating flow is not objectionable, a packed type, ball check, reciprocating pump may be used to meter with good accuracy. A system to meter water to a high hold-up mixer, for instance, could use a pump of this type to advantage.

If the equipment must be completely and quickly dismantled for cleaning, the metering device is frequently a gear-type single or double-lobe pump. This type of pump inevitably has high slip and cannot be used to meter low viscosity liquids accurately. Water with a viscosity of one centipoise, for instance, could not be metered accurately with such a pump, as any variation in discharge pressure would cause a variation in amount of slip or bypass in the pump, and an inversely proportionate change in discharge rate.

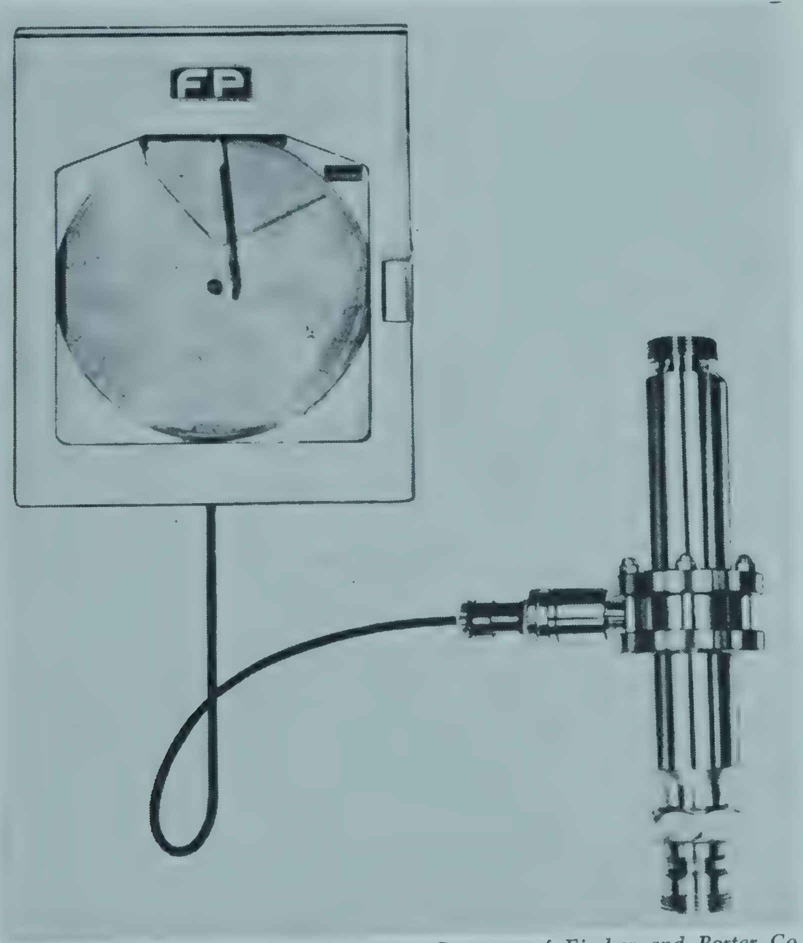
It should be pointed out that the gear-type sanitary pumps were not originally designed for metering, but many attempts have been made to meter with them. High viscosity, flowable liquids such as cake batter can be metered with these pumps, with accuracy acceptable in the bakery, provided the discharge pressure is not varied more than ±10 per cent and provided *the pump inlet is not starved.* A Waukesha pump of the type shown in Fig. 59 makes a quite adequate meter to feed unaerated angel food cake premix into a mixer operating at 80 to 90 p.s.i.g., if the feed to the pump is open and unobstructed.

In some continuous bakery mixing operations two gear pumps are installed in tandem to meter liquid and air to a mixer for producing a foamed product such as marshmallow topping. The downstream pump runs faster than the upstream pump, drawing in a roughly metered quantity of air through an open intermediate valve.

One problem in metering viscous premixes with pumps is pump starving due to a restricted feed line. If the premix contains dispersed air, and if reduced pressure at the pump intake causes a bubble to form, the pump will bind completely. A good solution is pressure feed, either by gravity with oversize lines, or with a booster feed screw, as in the new continuous bread-making systems.

Some cake bakers have applied the pressure-fed metering pump principle in an interesting, if cumbersome, way. A submersible compressed-air operated reciprocating pump is lowered into the premix bowl and connected by large inside diameter rubber hose, to feed the metering pump. This shortens the "suction line" to zero and puts the whole system under positive pressure. In this system it is important not to omit the positive displacement, constant-speed metering pump, as the delivery rate of the air-operated booster pump is greatly affected by the viscosity (and hence temperature) of the feed batter.

Variable area meters.—Variable area meters (rotameters, Flowrators, etc.) are used to meter bakery fluids continuously, particularly following a reasonably constant-rate pump. The variable area meter consists of a vertical, tapered tube, smaller at the bottom than at the top, containing a solid "bob" or float. Liquid is pumped up through the meter, lifting the bob. As the bob lifts, the annular flow area around it increases. For steady flow rate the bob will stay in an equilibrium position at some point in the tube. The height of the bob in the tube indicates the flow rate.



Courtesy of Fischer and Porter Co.

Fig. 60. Automatic Recording Flowrator for Metering Liquids Continuously

Indicating Flowrators have transparent, calibrated tubes, and give an excellent visual indication of flow rate, which is controlled by manual adjustment of a throttling valve or the feed pump speed. Recording models are available, as shown in Fig. 60. An inductance type pick-up sends a signal to an automatic recorder. The signal is proportional to the height of the metal bob. With suitable instrumentation, the signal can be used to operate a throttling valve in the fluid feed line, or a variable speed transmission on the feed pump, to give automatic feed-back flow control.

Variable area meters perform well on all thin non-viscous liquids, and all gases, such as the air stream for a cake batter mixer. But they cannot be used to meter viscous, stringy, or tacky liquids. They meter water, milk, and light oil well, but cannot meter batter or dough accurately.

Miscellaneous Types of Fluid Meters.—Other common fluid flow-measuring devices such as orifices, Venturi meters, and Pitot tubes, have found no acceptance in measuring bakery process streams, perhaps because pressure-sensing leads are too easily plugged or contaminated.

A final word may be warranted about metering plastic shortening, which in a sense is neither fluid nor solid. As already pointed out, liquid shortening can be used for bread dough, and metering is no problem. However, high quality cakes require aerated, plasticized shortening, and this is difficult to pump and meter. If it is really important to meter this type of shortening *continuously*, it can best be done, at relatively high first cost, with a Votator heat exchanger. The shortening is metered in a molten, liquid state, with a suitable pump, into a Votator scraped-surface heat exchanger, with the correct rate of air. The Votator system aerates and chills and crystallizes the shortening, and delivers it through a discharge pipe, to the desired point. As long as the shortening is kept moving in the plastic state, it is flowable.

PREMIXING AND BLENDING

A bakery "premix" is a combination of ingredients that must undergo additional mixing before processing is complete. Usually the bakery premix contains only a part of the total ingredients for a product, but it may contain all, or all but the gaseous ingredient, air. "To premix," for the purpose of this discussion, is to form the premix.

In the bakery processes there are some situations in which a premix of part or all of the ingredients is desirable, and other situations in which a premix is indispensable. Premixing is used to accomplish several different objectives. Some of these will be reviewed generally in the following discussion.

Advantages of Premixing in Batch Operations

Premixing for Uniform Distribution of Micro-ingredients.—When a very small quantity of one ingredient is to be mixed thoroughly into a large viscous mass of other materials (such as bread dough), it is advantageous to distribute the small ingredient throughout the larger mass as well as possible, at low expenditure of energy, prior to attempting the final mixing operation. This saves time and energy. If the minor ingredient is charged only at one point in the mass it will require a longer time for complete distribution, since there must be so much interchange of material within the mass to effect distribution.

In bread dough mixing it is common to premix the minor ingredients with one of the major ingredients, partly to assure uniform distribution of all ingredients in the available mixing time. It is inferred here that the final mix is "difficult" and the premix is "easy."

If for instance it were necessary to make a large uniform mix in minimum time of 100 parts of flour, 60 of water, and one of sugar, a heavy, powerful mixer would be required. If all three ingredients are charged at once, and the sugar is concentrated at one point initially, it will take longer to be distributed than if it is pre-dissolved in the water—a relatively easy, inexpensive operation.

Obviously, if it were necessary to make a mixture of 100 parts of alcohol, 60 parts of water, and one of sugar, there would be no point in premixing, since the final mix is easily made in one step.

Reducing Multiple Scaling Operations.—When an ingredient batch contains several materials present in small quantities, and several consecutive batching operations are scheduled, it may be advantageous to premix one large batch of the minor ingredients in the correct ratios, and use a calculated quantity of this premix in each final batch. This saves a large number of weighing operations and reduces the frequency of errors in ingredient scaling. To be advantageous, the premix must be easy to form, store, convey, and meter. A pumpable, aqueous premix containing dissolved or dispersed minor ingredients is an example.

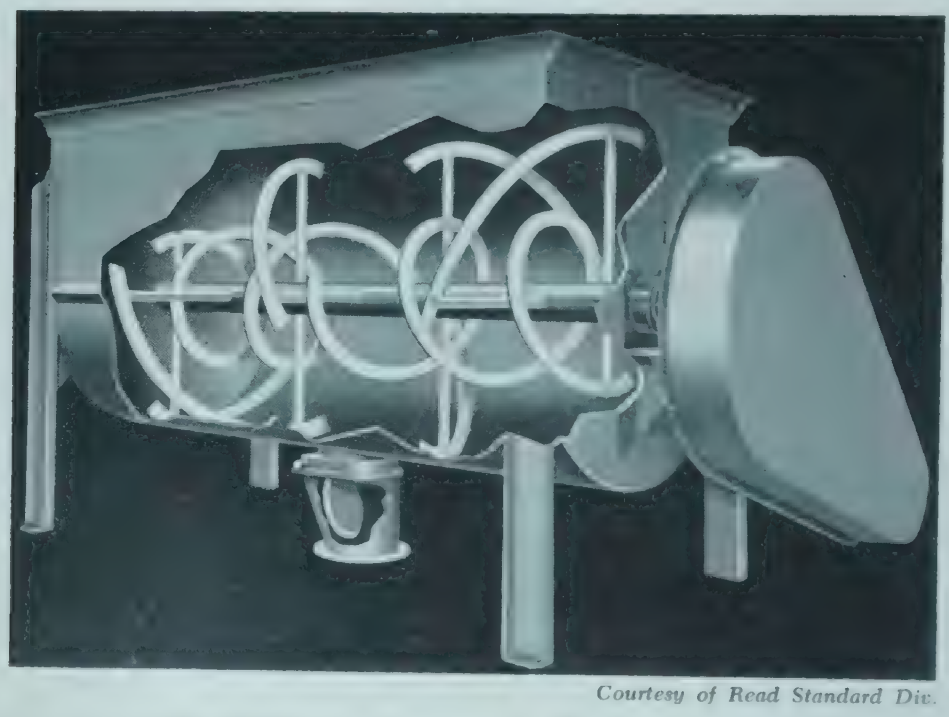
Premixing for Mechanical Efficiency.—When one or more ingredients require high shear action to disperse them, and the final mix is of low viscosity, completion of the mixing operation is difficult when all ingredients are present. It may be hard to disperse the lumps if the mix is too thin. In this case it is desirable to make a viscous premix of all solid ingredients and a small portion of the liquids, adding the major part of the thin liquids in the final mixing stage, after the lumpy solids are well dispersed in the viscous premix.

Premixing for Convenience in Shipment and Ultimate Use.—For various industrial, military, and domestic end uses, prepared bakery mixes are made up in large batches, to save time and labor at the point of use. For most bakery products it is not possible to ship a complete mix, since it would be unstable, difficult to handle (require special storage conditions) and would require shipping of water, which is usually available at the point of use.

Consequently dry premixes are prepared by methods and equipment to be described later.

Advantages of Premixing in Continuous Operations

Premixing for Economies in Equipment.—It is possible to feed a continuous mixer by metering each individual ingredient stream separately, through its own gravimetric feeder. Relatively accurate metering is necessary since the continuous mixer must always contain the correct proportion of ingredients, within tolerable limits. This practice usually requires more equipment and is more expensive than an alternate prebatching procedure.



Courtesy of Read Standard Div.

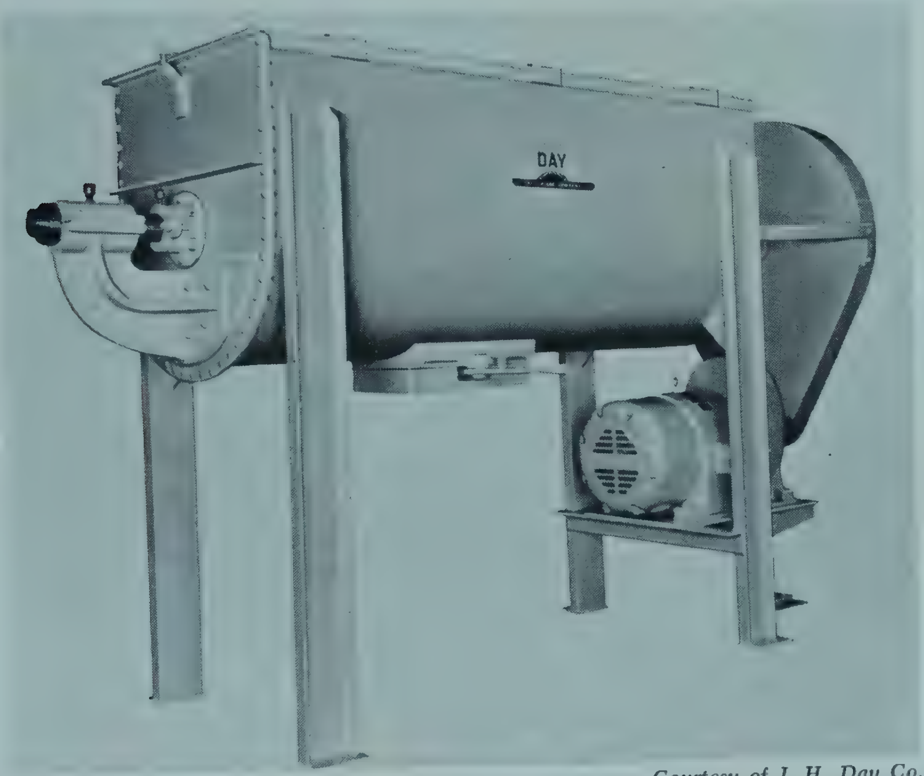
Fig. 61. Ribbon Blender for Dry Ingredients

An economy results if several ingredients can be combined in a premixed batch into one feed stream that is easily metered. For instance, all of the solid water-dispersible ingredients in a bread dough formula can be dispersed in the water fraction and metered through a pump or Flowrator, to avoid providing a separate gravimetric feeder for each ingredient.

Premixing to Put Materials in a Handleable Form.—It is impractical to feed dry materials directly into a continuous mixer operating at a pressure appreciably above atmospheric. It is simpler and more convenient to feed to an open, atmospheric premixer, and combine the ingredients into a pumpable slurry, that can be easily introduced to the pressurized continuous mixer. An open, screw premixer-feeder can be used, or if the mix is flowable enough, a twin-cone blender is effective.

Premixing Procedures

Premixes of Solids.—Premixing of flour, sugar, milk powder, dried eggs, chemical gassing agents, etc., is necessary in the processing of prepared bakery mixes. If no shortening is to be added, satisfactory blending is easily accomplished in blenders of the tumbling barrel type. Standard equipment in the industry, however, is the "ribbon blender," as shown in Figs. 61 and 62. This batch mixer has a long, horizontal trough-shaped bowl with a horizontal agitator shaft passing through axially. Helical steel ribbon agitator elements are fixed to the shaft by radial supports, and as the shaft rotates, these agitators lift and displace the mix axially and radially. The discharge port is at the bottom center of the bowl.



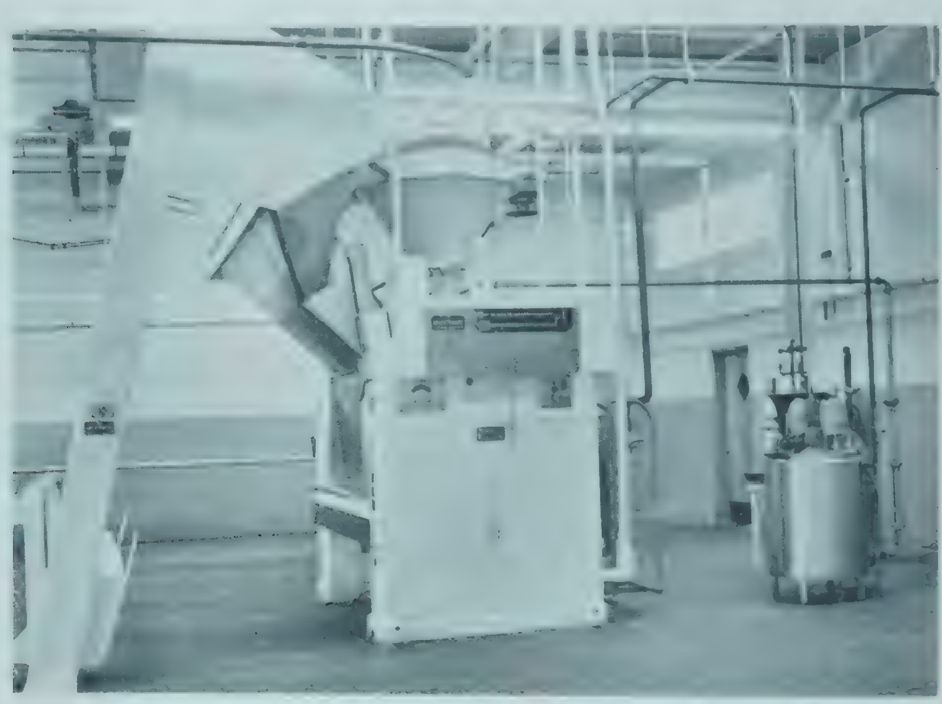
Courtesy of J. H. Day Co.

Fig. 62. Blender for Dry Ingredients

One advantage of the ribbon blender is that it is available in a very wide variety of sizes; from a one cubic foot, fractional horsepower unit to 500 cubic foot, 50 horsepower units. Larger mixers are designed and built to special order.

When shortening is to be blended into the dry mix (the usual case) requirements are somewhat more exacting, but the mixing can be accomplished in conventional horizontal double arm mixers, in ribbon blenders, or in vertical planetary type mixers. Ribbon blenders are standard and represent the highest ratio of capacity to capital investment.

To make up a premix containing dry ingredients and shortening, the dry ingredients are first charged to the mixer and blended briefly. Then oil or liquid shortening is pumped to a manifold feeding a row of atomizing spray heads mounted above the mixer so that the spray impinges on the dry solids as they are turned over by the agitator. The mixing action continuously exposes a fresh surface to the shortening spray, and the dry particles are coated with oil or crystallized shortening.



Courtesy of Baker Perkins, Inc.

FIG. 63. HORIZONTAL DOUGH MIXER SHOWING TROUGH HOIST, CHUTE, FLOUR WEIGHER, AND INGREDIENT HOPPER

On the extreme right is a Readco Ingrediator.

With some cake mixes plastic shortening must be used. It is pumped through a tee-manifold and extruded in spaghetti-like strings into the dry mix. The agitating action breaks up the shortening into discrete particles, and disperses it finely into the mix.

In a typical installation, a 3000-lb. batch is prepared in a ribbon blender of at least 75 cubic foot capacity. The mixing cycle extends approximately seven minutes past the time that the last shortening is added.

Premixes of Fluids and Solids.—In the conventional batch mixing process for bread dough, small ingredients are pre-blended into a portion of the water, in emulsifying equipment of the type shown in Fig. 63. In this figure is shown a Readco Ingrediator, which consists of a small vertical stainless-steel tank with a direct-driven high speed agitator. When the tank is charged with water, the agitator creates a vortex that draws in the dry powdered materials, wets and dissolves or disperses them. Emulsification of the small ingredients in the water fraction assists in distributing them evenly in the sponge or dough mass.

The shortening may be incorporated in a liquid phase pre-blend if the mixture is subjected to an adequately intense emulsifying action. Anderson and Mullen (1951) have reported work in which such premixes were made up in 1500-gallon stainless-steel tanks and apportioned to a large number of white dough mix batches. Use of this large batch eliminated many repetitive weighings of small ingredients. A Manton-Gallin homogenizer reduced the undispersed particle size in the premix enough to make the emulsion sufficiently stable so that it could be held throughout an operating day, to supply the small ingredients for the entire production of white doughs.

This method appears to have considerable merit and though used commercially in one installation with notable success, has not come into general use. This may be due to the increased use of automatic remote-controlled scaling systems in new bakery plant installations. It is not to be confused with the "liquid ferment" process, in which a large batch of refrigerated, prefermented "brew" is metered to conventional batch mixers to make straight doughs.

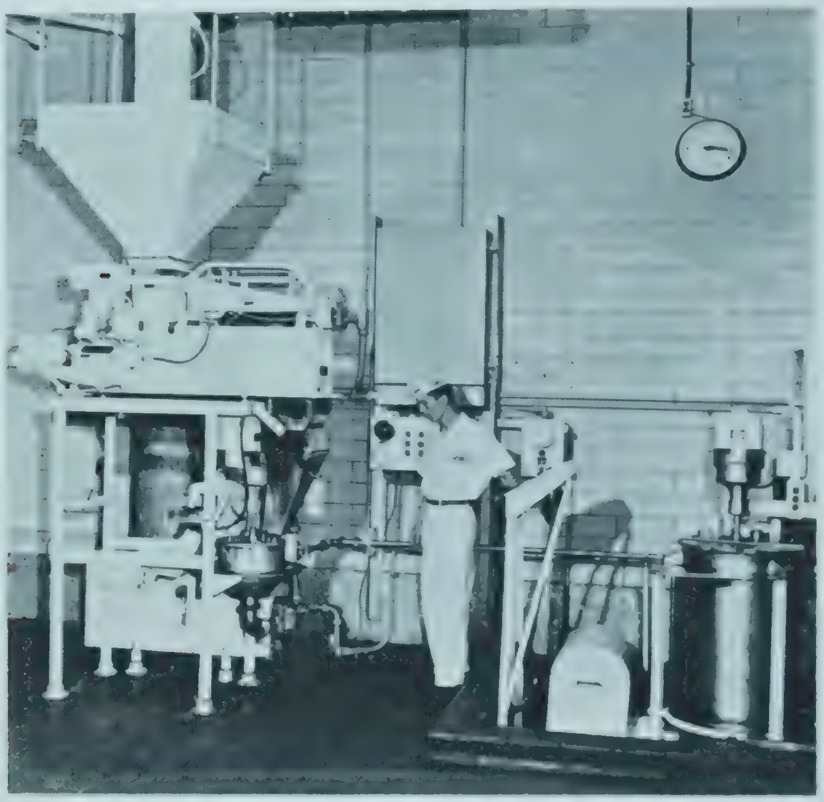
It may safely be said that premixing is of definite benefit to the conventional batch dough mixing process, but it is not essential to the process. On the other hand, premixing is indispensable to the continuous bread making process as presently concerned.

It would be impractical to introduce the flour into the pressurized developer head without first mixing it with some of the liquid ferment to form a pumpable slurry. The slurry is put in a continuous screw mixer-feeder, and force-fed to the positive displacement dough metering pump.

In the batch cake mixing process for shortening-type cakes, premixing has been practiced for years, though it has normally been thought of as stage mixing, and will be discussed under the section on mixing in this chapter.

Premixing is essential to the continuous cake mixing process, and may be done in one or two stages, depending on the nature of the process, and the type of cake being mixed. The purpose of the premix is to provide a continuous feed to the final mixer containing the proper proportion of each ingredient except air. The air also could be incorporated in a premix of sufficiently high viscosity, but it would be difficult to control the specific gravity and hence the metering rate of the premix.

It is not necessary that the cake batter premix be completely homogeneous as it is fed to the final mixer. It may in fact, contain shortening lumps one-half inch in diameter and that in itself would not affect the character of the final cake product. If the continuous mixer provides sufficiently high hydraulic shear, the lumps will be completely dispersed, and it is only necessary that the feed from the premixer be uniform in the overall composition of samples approximately the size of the hold-up in the final mixing head.



Courtesy of American Machine and Foundry Co. and American Stores, Inc.

Fig. 64. Premixing Section of a Continuous Cake System

In most continuous cake mixing systems the premixer is a large batch type planetary vertical mixer. A 500-lb. premix can be formed in as little as three minutes. It is then pumped to a holding tank before being metered through the final system. This seems like a redundant system since the premix can be made in much less expensive equipment and the fine homogenizing effect of the planetary mixer is not needed. However this type of batch mixer is standard and most cake shops have had one or more units in operation before graduating to a continuous system.

In the absence of the vertical mixer, a less expensive double-acting agitated kettle may be used for any cake premix. Or, for the highly aerated cakes such as sponge cake and angel food cake, all that is required is a propeller agitated tank of suitable size and shape.

For heavy, shortening type cakes, a two-stage premix works well, as shown in Fig. 64. Provided easily emulsifiable shortening is used, all ingredients except flour and air can be batch premixed in a vertical tank with high speed propeller agitation. This liquid premix is then metered with a Waukesha pump to a Disc Blender, along with a stream of flour from a gravimetric feeder. The Disc Blender is a low hold-up, highly efficient premixer containing a twin-cone agitator that maintains an open vortex and incorporates dry ingredients much more effectively than does a propeller type agitator. The premix is pumped out of the bottom of the Disc Blender bowl, into the final mixer.

MIXERS AND MIXING PROCEDURES FOR DOUGHS AND BATTERS

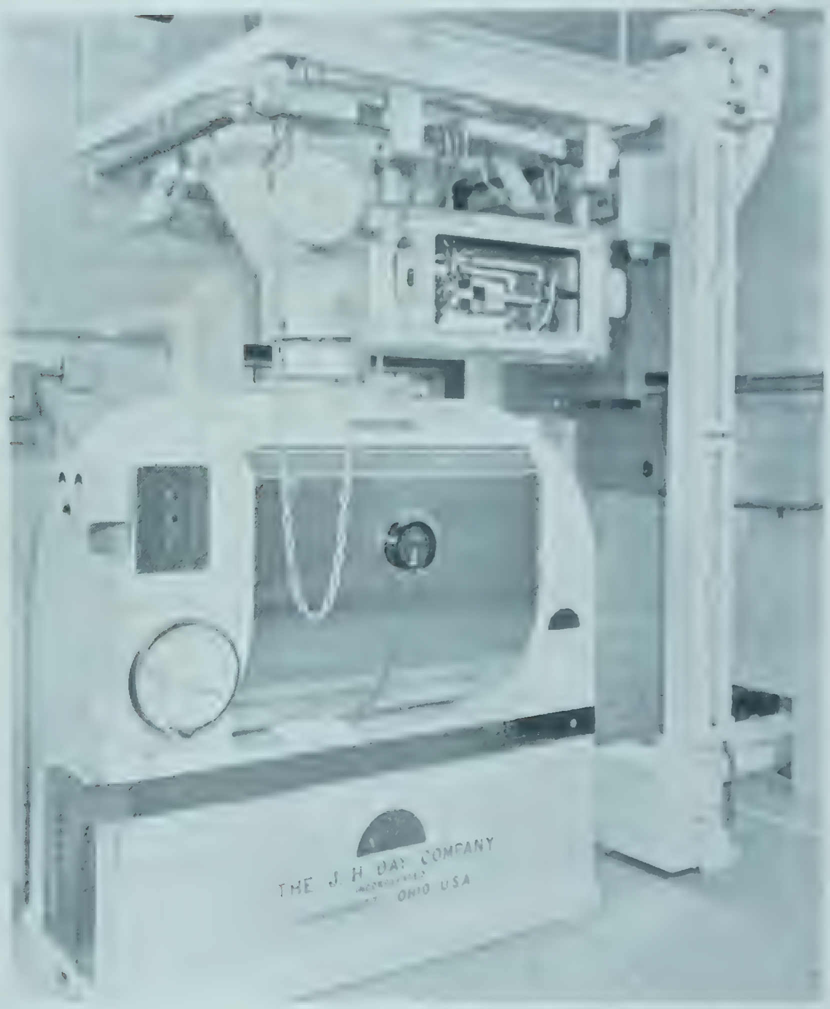
Most of the operations in the bakery are specific to the manufacture of baked products. Mixing is an exception, and is the only bakery operation classifiable as a chemical engineering unit operation. As such it has been thoroughly studied in its simpler applications by many investigators. A fairly consistent body of data has been accumulated, relating power input to mixer design and operating variables, in simple equipment, mixing near-ideal liquids.

Conversely there is little to go on in the design and development of new mixers for highly viscous, pseudoplastic materials, except intelligent trial and error in an experimental course steered by practical experience.

The main reason for this is that the factors affecting mixing of these materials are complicated. For instance, in a given mixer operating on a given mixture of dough or batter, two of the most important variables affecting power input, viscosity and mixing velocity, *are closely interdependent.* The apparent viscosity decreases with increasing rate of shear. Furthermore, it is almost impossible to define the relationship mathematically for purposes of equipment design, since the equipment must process several different formulas of dough, and each represents a different relationship between viscosity and mixing velocity, and hence, power input.

Perry (1950) gives a good discussion of the fundamentals of mixing, including clear definitions of the various types of liquids mixed: ideal, plastic, pseudoplastic, thixotropic, dilatant, and rheopectic.

Doughs and batters are principally pseudoplastic. The same source gives this good definition of the object of mixing: "In all cases, two or more materials existing either separately or in an unevenly mixed condition are, by mixing, to be put into such a condition that each particle of any one material lies as nearly adjacent as possible to a particle of each of the other materials."



Courtesy of J. H. Day Co.

FIG. 65. SMALL HORIZONTAL DOUGH MIXER WITH FLOUR CONVEYING AND BATCHING SYSTEM

In bread dough mixing there is another objective that may lie quite apart from this. Apparently it is necessary to knead the dough to develop gluten into elongated fibers, so it can form a structure capable of retaining dispersed gas to give a light loaf of bread.

It is safe to say that the theoretical aspects of the unit operation of mixing have been of little help to equipment developers, except possibly in scale-up of equipment to larger models of the same design.

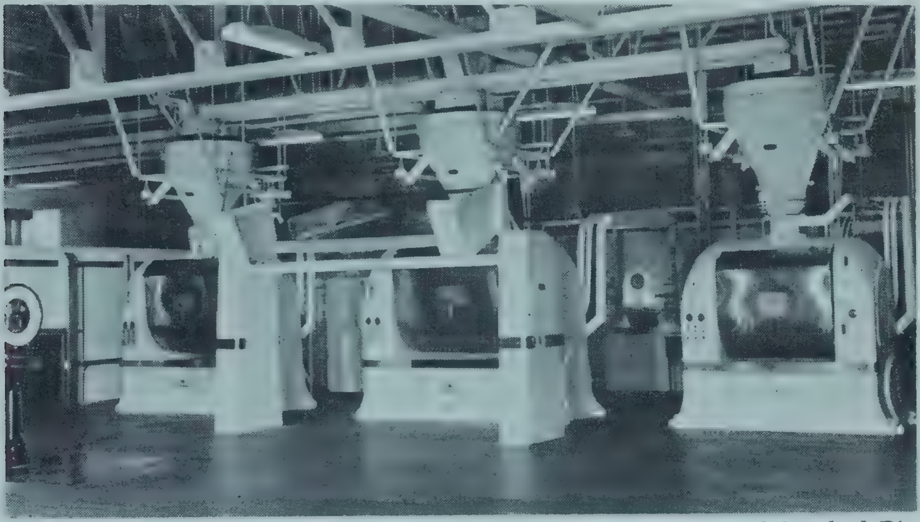
Dough was being mixed long before Reynolds defined his dimensionless number, so essential to all current studies of fluid flow, and equipment designers have evolved an impressive family of successful dough mixing machines, for the most part without knowledge of Reynolds' contribution.

Still it is to be hoped that the basic theoretical concepts can be applied to the known art to develop empirical relationships helpful in development of yet more efficient machines to mix obstinate materials such as dough, and that the trial-and-error approach will be replaced by the scientific approach, as it has in so many other technologies.

Mixers for Doughs—Batch

Of the 11,000,000,000 lbs. of commercial bread dough mixed in the United States each year, all but a very small fraction is mixed in horizontal dough mixers of the type shown in Figs. 63, 65, 66 and 67.

There are many hundreds of these mixers in daily operation—mixing all types of yeast-raised doughs—and in more than one instance units have been in almost constant use for 30 years.



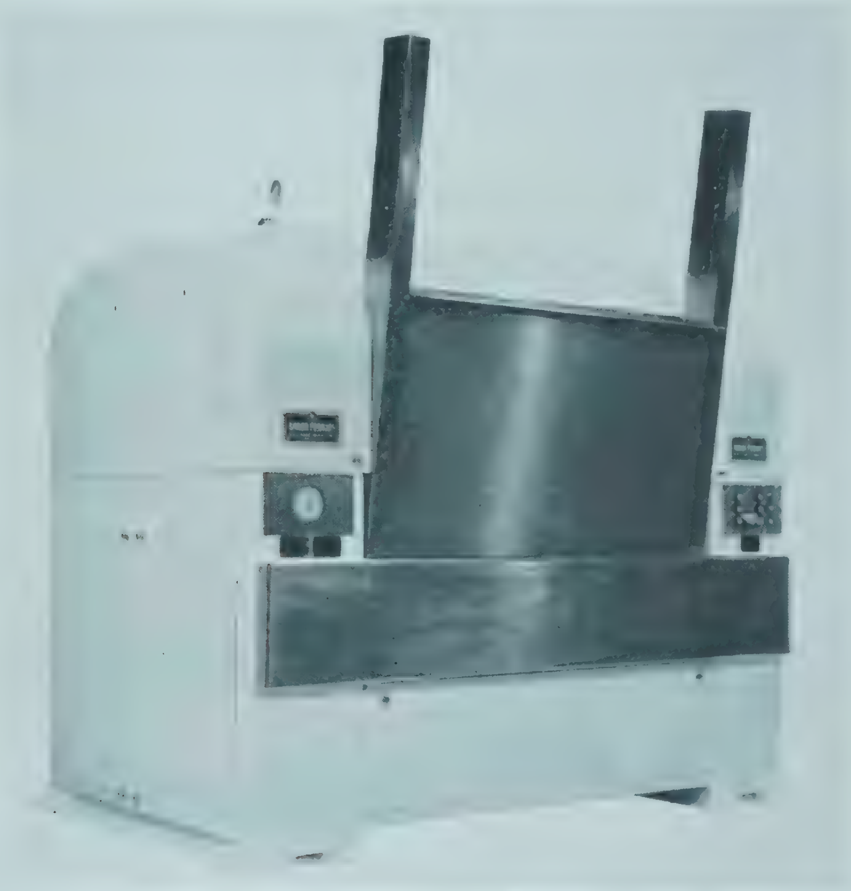
Courtesy of Read Standard Div.

FIG. 66. BATTERY OF HORIZONTAL DOUGH MIXERS

At least eight American manufacturers offer mixers of this type to the industry, and whether they are used to mix sponges, doughs, straight doughs or "liquid ferment" doughs, the mixer construction is generally the same. A horizontal mixing bowl, U-shaped in cross section, is mounted in a rigid frame over the drive motor and transmission. In some mixers the bowl is tilted by a separate motor to discharge and in others a front load door is dropped to discharge. A single horizontal agitator shaft passes through the bowl axially, and is driven with a sprocket and chain drive from the transmission below. Mixer arms are mounted on two spiders on the agitator shaft. The various mixer models have 2, 3, or 4 arms, one or more of which may be free rolling. Some mixers have stationary braker bars or baffles mounted in the bowl parallel to the agitator shaft.

A wide range of mixer sizes is offered. The most common mixers are Nos. 8, 10, 13 and 16. The numbers refer to the approximate maximum dough batch capacity in hundreds of pounds.

Two-speed motors are usually provided for high and low speed operation. Table 69 shows relative physical characteristics of typical horizontal mixers. The No. 20 mixer was a special design for a particular high capacity installation.



Courtesy of Baker Perkins, Inc.

FIG. 67. LARGEST SIZE OF HORIZONTAL DOUGH MIXER

Bowls and bowl covers have been fabricated of mild steel in the past but the use of stainless clad or full stainless bowls is growing. Bowls are provided with jackets for circulation of coolant fluid.

Auxiliary equipment for horizontal dough mixers includes flour batching weigh hoppers, mounted overhead and discharging through a mixer cover opening, liquid ingredient dispensing systems (piped through the cover), trough elevators and chutes for charging sponges to the mixer, and refrigeration systems for bowl jacket coolant. Available instrumentation includes automatic mixing time controller, constant temperature indication, and recording-type power consumption indicators.

Quite a great deal of engineering effort has gone into the design of this mixer, and much of it has been directed toward improvement of sanitary features. The packing gland seals between bowl and agitator shaft have in particular received significant attention.

Although many mechanical improvements have been made in the horizontal mixer in the last 30 years, the mixing techniques are old and well developed, and a wealth of information is available from the various manufacturers, on operation and maintenance.

TABLE 69

CHARACTERISTICS OF BATCH-TYPE HORIZONTAL DOUGH MIXERS[1]

Mixer, size no.	10	13	16	20[2]
Maximum capacity, lbs.	1000	1300	1600	2000
Minimum capacity, lbs.	500	650	800	...
Agitator horsepower	15/30	20/40	25/50	37.5/75
Agitator speed, r.p.m.	57/75	35/70	35/70	35/70
Compressor horsepower	15	15	20	20
Actual bowl volume—cu. ft.	41.2	50.6	61.6	79

[1] Courtesy of Baker Perkins Inc.
[2] Special oversize mixer.

The action of the agitator bar on dough ingredients varies through the mixing cycle. The first 2 or 3 minutes—while the flour is being wetted—is the least efficient part of the cycle mechanically, but it is necessary to the process. When enough of the flour has been wet, a sticky ball of dough is formed and rotated around the agitator shaft by the action of the mixer arms. This ball grows as it "cleans up" the ingredients sticking to the inside of the bowl, until the agitator "picks-up" the whole mass and rotates it around the shaft. From this point on, the agitator rolls, folds, and kneads the dough, stretching and shearing it to disperse and moisten dry lumps, to disperse gas bubbles, and, we are told, to "develop" gluten. This action is more efficient mechanically but there is still a waste of energy, inherent in the system, in the lifting, throwing, and slapping around of the dough mass—actions that use power but contribute little to mixing the dough. The cost of power *per se* is not a significant item in the mixing operation, however.

Mixing times for various doughs in different plants run 10, 11 and 12 minutes, with a typical cycle of four batches per hour. The point of completion of mixing is the point of maximum power input to the mixer. Mixing beyond this point reportedly results in breakdown of the gluten and a progressively lower power input.

Horizontal mixers handle all types of yeast-raised doughs, including bread, roll, and sweet-goods doughs.

The bread produced from dough mixed on this equipment is the conventional product of relatively coarse, heterogeneous grain, accepted as "normal" by the industry. That this "normal" grain is as much a function of the mixing action as of any other process variable is a fact that was generally overlooked until the recent activity in continuous mixer development.

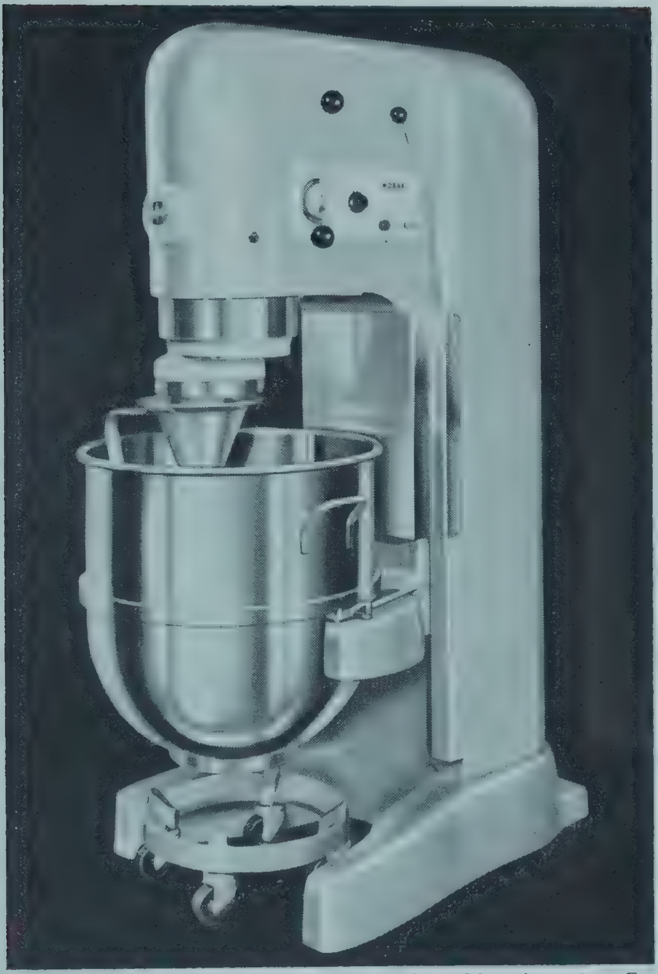
One result of the shearing action in the dough during mixing is the generation of heat. Most of the work done by the mixer motor shows up quantitatively in the dough as sensible heat, and if this heat is not removed during mixing, the dough may leave the mixer at a temperature above 100°F. That would make operation of the conventional dough make-up equipment difficult. The dough would gas at a higher rate than usual, and the difference in performance of the first part and the last part of the batch in the divider, rounder and moulder would be pronounced. Hence it is necessary to use chilled ingredient water in the mixer, and to cool the dough as much as possible during mixing.

Auxiliary equipment is available for these tasks, designed specifically for use with dough mixers. Ingredient water chillers using vapor compression refrigeration equipment are provided by mixer manufacturers. The mixer bowls are provided with jackets, for chilled water in some designs, and for direct expansion of refrigerator coolant in others. The direct expansion units seem more popular, and are available in sizes up to 25 horsepower for the largest mixers.

Mixing of pie doughs introduces a special problem in that a very low degree of overmixing results in a tough pie crust. For this dough a special mixer, the Artofex, has been designed to use a change type bowl automatically rotated in the mixer, and agitators that closely duplicate the action of human hands. The object of mixing this pastry dough is merely to put the dough together. Kneading and rolling to develop gluten are carefully avoided. This special mixer apparently gives the desired results in commercial pie dough production.

It is possible and practical to mix small batches of yeast-raised dough on vertical, planetary action mixers of the type shown in Fig. 68. These machines are discussed in more detail in the section on mixers for batters. Some retail bakers who need one utility mixer for all products mix sweet goods, pie doughs, and even bread doughs on them. In a few cases wholesale bakers mix sweet yeast-raised doughs in batches up to 200 lbs., on the largest planetary mixers.

The agitator used on yeast-raised doughs is called a "dough hook." It is a single curved arm of bronze, aluminum, or stainless steel. The power



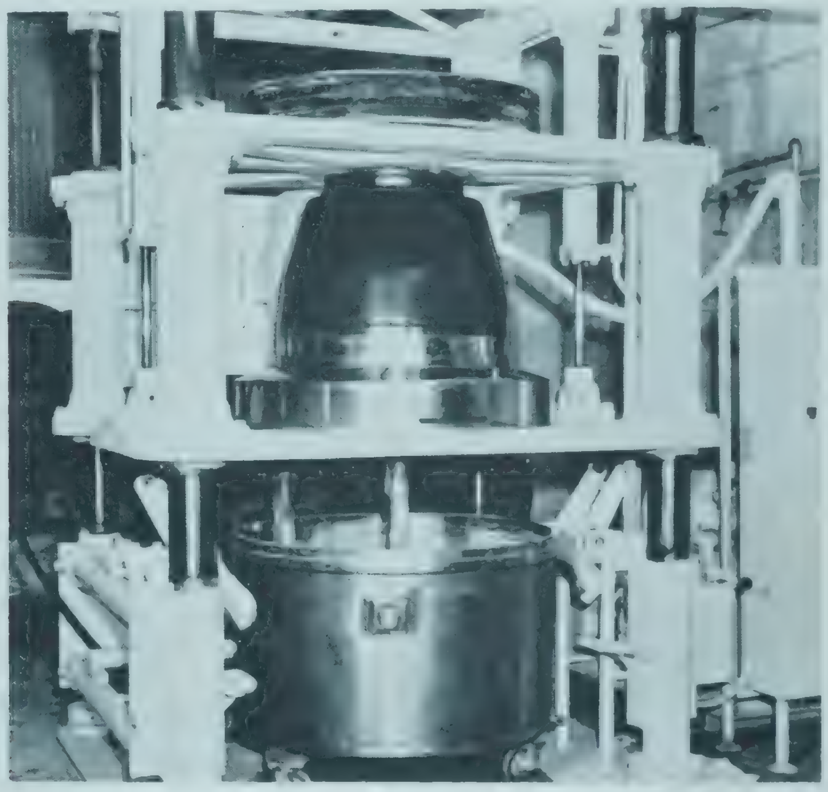
Courtesy of Hobart Manufacturing Co.

FIG. 68. LARGE VERTICAL PLANETARY CAKE MIXER

of the agitator drive, which is as much as ten horsepower on the largest units, operated at top speed, would not be sufficient to drive an agitator with two or more arms in bread dough. The type of transmission used in the largest cake mixers does not deliver the full horsepower of the motor at low speed. The mixing action is efficient, however, and the advantages of removable bowls are worth considering.

Another important batch-type bread dough mixer, the "Daymatic," promises to become much more widely used and merits discussion here. This equipment has been developed within the last ten years in the United States, although it bears similarities to some European mixers. In principle it resembles the planetary cake mixer more than it does the conventional horizontal batch mixer. In construction it is reminiscent of the early arch type large planetary cake mixers.

The stainless steel cylindrical bowl is caster-mounted and is moved in and out of the mixer, and through the fermentation cycle. It holds a maximum batch of 600 lbs. of dough. A stationary center-post and a double arm planetary agitator extend cantilever from the two speed, 56 horsepower overhead, planetary drive as shown in Fig. 69. The entire drive with its agitator is hydraulically raised and lowered to permit bowl replacement. At high speed the agitator rotates at 140 r.p.m. and the planetary head at 40 r.p.m., for a precession ratio of 3.67 (very close to that of the single-ratio planetary cake mixers). Low speed is one-half speed. Speed, mixing time and hydraulic lift equipment are controlled from a central panel.



Courtesy of J. H. Day Co.

FIG. 69. DAYMATIC BREAD DOUGH MIXER

Several bowls are used in the mixing cycle. At the ingredient scaling station a bowl is first charged with all the ingredients except sugar and salt, using conventional weighhoppers and meters. The bowl is then rolled into the mixer and the dough is put together with a short mixing cycle of 15 seconds at slow speed and 18 to 30 seconds at high speed. The bowl is then removed from the mixer, allowed to stand two and one-half hours, and is returned to the mixer. Sugar and salt are added, and the mixer operates 15 seconds on low speed and three minutes in high speed (on a white dough—less on whole wheat and rye). After this remix, the bowl stands 12 to 15 minutes, is discharged to the divider hopper, and is ready for a new charge of ingredients.

Maximum production rate on standard equipment of this type is approximately 6000 lbs. of dough per hour.

In this process a special conveyor carries dough from the divider directly to the moulder, and the conventional rounder and overhead proofer are eliminated.

There are a number of important differences between this equipment and the conventional horizontal mixing equipment. Many of the differences appear as advantages—a few as disadvantages, depending partly on the particular bakery operation.

Because the batch is smaller, more scaling is necessary *than for a larger straight dough.* However, all the ingredients are scaled at once, and in the process in which this new equipment is used, there is actually less scaling than in the conventional sponge and dough process with large horizontal mixers.

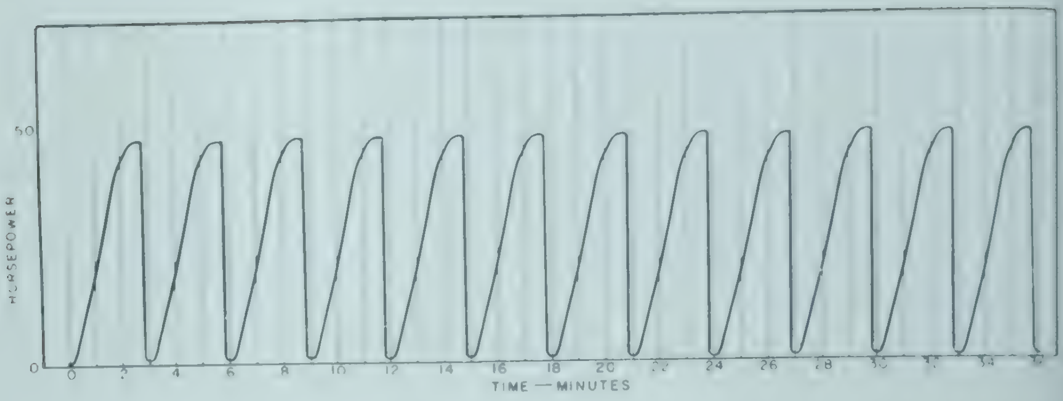
Because the dough ingredients remain in the bowls throughout the process, no troughs are used.

One factor that at first thought would appear to be a disadvantage is the impracticality of applying a coolant to the portable bowl, other than to use chilled ingredient water. However, there are several offsetting factors. The ratio of mixing action intensity to mixing time in this efficient, high speed equipment is so high that the heat of mixing cannot be removed through the available bowl area in the available time. Hence the dough is discharged at a relatively high temperature (92°F. for white bread). This is not the disadvantage that it would be in a 1600-lb. dough. Typically the batch goes through the divider in 6 instead of 15 minutes, and though it gases faster at the higher temperature, it is divided before it can become sufficiently bucky to cause more than ordinary scaling errors at the divider.

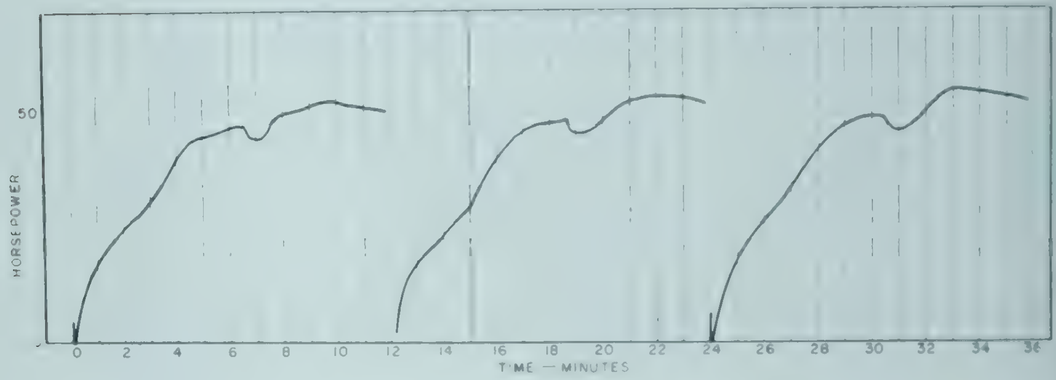
Elimination of the intermediate proofer cycle of 12 to 15 minutes results in a younger dough at the moulder. The higher dough temperature results in a much lower proofing time, since so much of the proofing time in the conventional proofer is used in bringing the dough up in temperature.

With this new mixing process, dough make-up is less critical and higher dough temperatures can be tolerated.

Among other advantages reported by manufacturers and users are: (1) easier equipment cleaning and faster variety change-over; (2) significantly lower over-all equipment costs for mixer and make-up equipment, and lower installation costs; (3) lower floor space requirements; and (4) labor saving.



600 LB. BATCH IN DAYMATIC MIXER



1600 LB. BATCH IN HORIZONTAL MIXER

Courtesy of C. J. Patterson Co.

Fig. 70. Curves Showing Power Consumption of Batch Type Bread Mixers

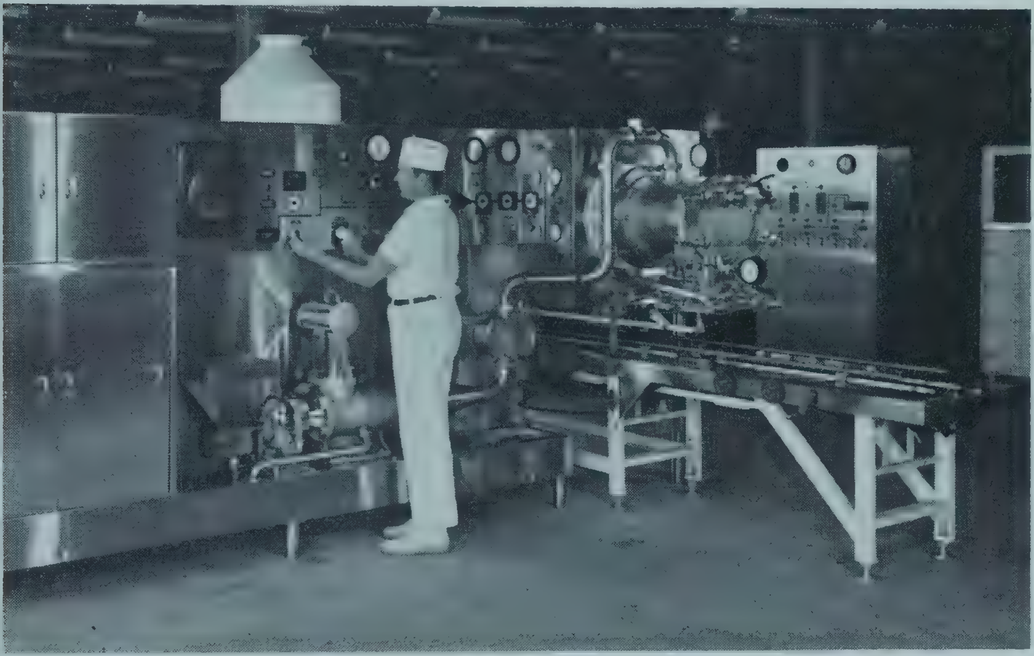
The curves of Fig. 70 show relationships between the power consumption of the Daymatic Mixer and a No. 16 horizontal mixer. For an equivalent production rate, the Daymatic does less work. The sharp dips in the horizontal mixer curves mark points where salt was added to the mix.

Continuous Dough Mixers

References to continuous bread dough mixers in the United States usually refer to the complete *systems* developed by two or more United States manufacturers within the last 10 to 15 years. These systems include equipment for scaling, premixing, fermentation, mixing, depositing and panning. They replace, in the batch system, weighhoppers, ingredient emulsifiers, batch mixers, fermentation troughs and rooms, dividers, rounders, intermediate proofers and moulders.

These systems are more fully discussed in Chapter 18. This brief discussion will deal principally with the part of the system including the mixing unit components themselves, and only with systems currently in use. A comprehensive idea of the historical development of continuous mixing in the baking industry can be had from other sources including the patent literature.

The essential mixing units in the United States continuous systems are (1) the premixer, or incorporator, and (2) the final mixer, or developer, as shown in Fig. 71.



Courtesy of American Machine and Foundry Co.

FIG. 71. CONTINUOUS BREAD MIXING SYSTEM

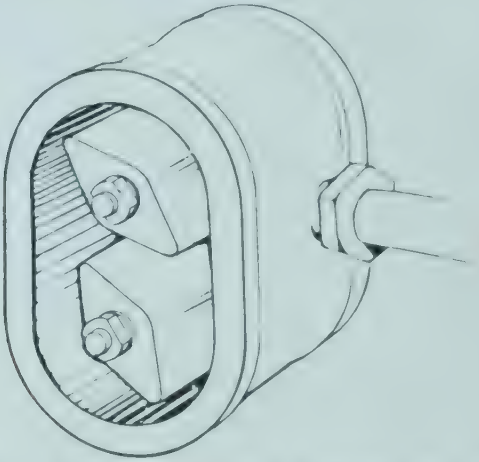
The premixer is a stainless steel screw in a long stainless cylindrical housing. Ingredients are delivered to the feed end of this screw in three or more streams and are roughly incorporated into dough and discharged by the screw under pressure at the other end.

The three major streams fed to the screw are (1) liquid "ferment" ("broth," "brew," or "liquid sponge"), (2) liquid shortening, and (3) flour. These ingredient streams are blended together and discharged through large stainless tubing to the inlet side of a stainless positive displacement gear pump. Since there is some slip in the screw, this force-fed pump is the basic rate-measuring device for the dough production system and it must be kept hydrostatically full.

It is not practical to synchronize all feed rates perfectly with this metering pump, so the feed streams to the screw are alternated in rate through a high-low cycle, with the high-rate time interval fixed, and the switch from high to low triggered by build-up of material in the screw feeder.

The metering pump forces the roughly constituted dough to the final mixer, or developer, through stainless tubing. This final mixer has an internal cavity, oval-shaped in cross section, with two counter-rotating double-arc paddle arms extending axially through the cavity. The diagram of Fig. 72 is typical, though it is not necessarily faithful to either of the commercial designs.

The dough mass enters the cavity near one end and exits near the other. A swing door opens in the front of this mixing head for access.



Courtesy of P. R. Bunnelle and Food Machinery and Chemical Corp.

Fig. 72. Schematic Diagram of Continuous Dough Mixer Head

The dough exits from the head through a type of intermittently operated extruder slot that discharges a dough piece broadside and drops it into the pan below. This discharge device is synchronized with the pan feed conveyor.

Since the developer head will hold only a few gallons of dough, the average residence time in the head is less than one minute. The mixing action for this short period, however, is extremely intense and the dough emerges in a homogeneous, flowable condition.

The development of these continuous systems has taken a lot of time, money, and energy, and it is to be assumed that the beneficial results were predicted with sufficient accuracy to supply the incentive. Current interest in these systems is running very high.

One important reported advantage is more accurate scaling of dough pieces, than in the batch process. This is understandable when it is considered that all of the dough is precisely the same age as it passes through the extruder cut-off slot. There is no cyclic change from old, gassy dough, to new dough, as in a divider operating on a succession of dough batches.

Another reported advantage is a labor saving of at least two operators per shift.

The advantage which seems to be receiving the most attention, however, is a reported improvement in bread quality: notably more uniform, finer grain and texture, and a whiter appearing crumb.

These effects, like superior scaling accuracy, can be understood on consideration of the mixing action in the continuous systems. The extremely intense, efficient action produces a more intimate, uniform mix of all ingredients *including air and gas.* This results in fine grain. Fine grain means more and smaller gas bubbles, more total bubble wall area, hence *thinner* bubble walls and more tender bread. The fine grain accounts for the whiter appearing crumb. Fine grain products always appear whiter because the cells on the cut surface are relatively small and shallow, and show less shadow.

Aside from efficient mixing, an additional cause of grain uniformity in continuously mixed bread dough is that the continuous mixer operates on only one physical phase, whereas the batch mixer operates throughout the mixing cycle on two phases: the plastic dough phase and the gaseous phase above. The continuous mixer operates at 50 or 60 lbs. pressure and is hydrostatically full—with no gas-filled space. Hence all gas bubbles receive the same dividing and dispersing action in the mixing cycle and are more uniformly dispersed at the finish. (In fact, much more of the carbon dioxide is in solution in the dough water at 60 p.s.i., than in the batch process at atmospheric pressure.)

By contrast, in the batch mixer, the agitator constantly draws new, large gas bubbles into the dough during the mixing period, and bubbles drawn in near the end of the period do not have time to be completely dispersed. As a result, bread from batch mixed dough is generally coarser than that from continuously mixed dough.

It has been shown experimentally that a small batch mixer operated hydrostatically (i.e., completely full of dough)—will produce uniformly mixed dough, and that the dough will produce bread with the characteristic fine, uniform grain of continuously mixed bread. As far as is known, no commercial use has been made of this principle and it may be impractical to use commercially.

The continuous mixing systems discussed above were designed to produce white, commercial, American bread. This bread is relatively high in specific volume due to incorporation of gas in the dough and retention of the gas in the baking process. For proper gas retention the gluten in the flour must be well developed, and this is best done by the kneading action characteristic of dough-developing-type mixers discussed above.

In the European market there is reportedly less demand for light, fluffy white bread, and less need for highly refined gluten development equipment. Continuous bread dough mixers of relatively simple design have evolved recently in Europe.

The Strahmann continuous mixer (Strahmann 1959) is an example. This machine incorporates premixer and mixer-developer in one unit. An elongated cylindrical housing contains a rotating shaft concentrically. The shaft has a plurality of screw-type paddle-blade units spaced axially along it, which rotate with the shaft to drive dough ingredients fed to the inlet port at one end, toward the discharge at the other. Near the discharge end of the mixer, the paddle blades are separated along the shaft by perforated baffle plates, mounted concentric with the shaft, and rotated in a direction counter to that of the shaft.

The action given by this mixer is an intense shearing, cutting, mixing action.

The baffle plates may be provided with any of a variety of shapes of perforations to give the desired effect. The Strahmann mixer has not yet gained acceptance in the United States bakeries though it has reportedly been used for some years in Germany.

Another European continuous mixer, the Ivarsson mixer, uses an ingeneously modified horizontal screw agitator to mix, knead and propel the dough through the cylindrical casing. After discharge from the mixer the dough is reportedly proofed and then sent through conventional dough make-up equipment.

In a recent development sponsored by the U. S. Army Quartermaster Corps, a small continuous mixer has been developed to combine chemically leavened prepared bread mix with water to form dough at the rate of 150 to 300 lbs. per hour. This mixer is for field use and is necessarily light, compact and simple. The dry mix metering feeder is volumetric, and gives sufficient accuracy to keep the finished dough within acceptability limits. The premixer is a screw, which force feeds a Waukesha type metering pump. The pump forces the roughly-mixed dough through the developer, a schematic drawing of which is shown in Fig. 72. The developer head operates under 40 to 60 p.s.i.g., and dough is extruded from the discharge end, through a rubber hose, directly into the pans.

Because there is no conventional dough make-up equipment in this process, variations in the absorption rate are not as critical as they might otherwise be, and the volumetric dry feeder gives adequate accuracy. There is no cooling on the developer head, and the dough issues much warmer than in the conventional process. This merely shortens the baking time, however, and is not a source of difficulty in the absence of the usual dough make-up procedure.

Mixers for Batters

Batch Type.—Mixers discussed up to this point were for mixing of yeast-raised doughs from strong, high gluten flours. The mixing of cake batters requires a different agitator action.

For purposes of discussing mixers, at least, cake batters divide roughly into two types: (1) "shortening" type cakes, including layer cake, pound cake, cup cakes, etc., and (2) sponge type cakes including conventional sponges, chiffons, and angel food cakes.

Generally the same mixing equipment is used for both types, but the different mixing actions needed are achieved with different agitators and different agitator speeds.

The vertical, planetary, change bowl type mixer shown in Fig. 68 is used universally for the batch mixing of all types of cake batters. This general type of mixer is produced by four or more United States manufacturers, and it may be obtained in bowl sizes of 20, 40, 80, 120, 140, 160 and 340 quarts. In wholesale bakeries the 140 and 340 quart sizes are most often used.

The agitator or beater action is described as "planetary" because the beater has two motions: it revolves on its own vertical axis at a relatively high speed, and its axis is rotated around the inside of the bowl at a relatively lower speed in the opposite direction. With a rubber-edged beater the entire inside surface of the bowl is wiped progressively as the planetary cycle is made.

Bowl hoisting and dumping equipment is available for the largest mixers. Some units have four positive speeds, from low to high, and some have infinitely variable speeds. On the larger units the bowls and mixing heads are raised and lowered automatically with an auxiliary motor.

On a 340 quart mixer of this type, the beater speed is infinitely variable from 45 r.p.m. to 325 r.p.m. The planetary action is slower: 25 per cent as fast (4 to 1 precession ratio) in the standard single ratio machine. In the dual ratio machine, a selection can be made between 4:1 and 2:1, or, the planetary action can be stopped completely, to create a vortex for addition of dry materials.

Beaters used for shortening type cakes are either two-wing or four-wing, shaped to fit the bowl side-wall and heavy enough in construction to withstand high starting torque. Frequently this stainless steel or cast aluminum beater has a white rubber insert in the edge, for contacting the inside of the bowl wall.

In the past it was the practice to mix a shortening-type batter in three or more stages, beginning by slowly creaming the shortening, flour, sugar and eggs together to emulsify all shortening and flour lumps before slowly cutting in the water. This procedure was necessary to effect the desired emulsion, and prevent the breaking of the emulsion as the water was added. However, the use of aerated, plasticized shortenings containing natural emulsifiers has changed this procedure somewhat. Except in the case of white cakes containing no egg yolks, the whole mix can be put together in two simple stages. The first stage, containing all the ingredients except the water, or two-thirds of the water, is mixed at low speed just long enough to achieve a consistency that will not splash out of the bowl. Then the speed is shifted to high and continued until all lumps are dispersed and a smooth, homogeneous batter is attained. The water is then added through an automatic meter and mixing is resumed—first at low speed to prevent splashing, then finishing at high speed.

The large 340-quart mixer will mix four batches of cake per hour, 400 to 500 lbs. per batch depending on consistency.

Most commercial cakes, even nominally "white" cakes, contain some whole eggs and can be mixed in this way. However, the pure white cakes are frequently mixed with a different cycle in which the water is cut in more slowly.

Whipped type cakes (sponge, chiffon, angel food), usually contain no plasticized shortening, although they may contain a small amount of oil. A major requirement is to whip a large amount of air into the batter to produce a foam of specific gravity down to 0.30.

The beater used is a wire whip shaped to conform to the inside of the bowl. Some models have center posts and others do not. The wires are $^1/_8$ to $^3/_{16}$ inches in diameter and are oriented to give the maximum turbulence.

In the large wholesale type vertical mixers, very thin batters, such as angel food batter, tend to swirl badly in the bowl unless baffles are placed in the bowl to resist the rotation of the liquid. Standard tinned baffles are available for the largest mixers, along with smaller diameter wire whips for use with the baffles.

The large dual-ratio AMF 340-quart mixer operating in the 2 to 1 ratio does not swirl the liquid, and no baffles are required. This mixer is very effective for foam type cakes.

These cake batters are batch mixed by first charging all the ingredients except the flour, and whipping at high speed until a light foam is obtained. The flour is then charged as quickly as possible and "folded in" at slow beater speed, breaking the foam as little as possible. If added first, the flour would inhibit the foaming action. It is not possible to produce a satisfactory angel food cake by whipping a mixture of all the ingredients including the flour. (This is not true of continuous mixers.)

The horizontal cake mixer, with kneader blades for shortening cakes and a squirrel cage whip for foam batters has been all but completely replaced by the efficient, versatile and sanitary vertical planetary mixers.

Another batch mixer that has gained some popularity for whipping cake batters, particularly angel food batters, is the Morton Air Pressure Whisk. This mixer is comprised essentially of a vertical tank with pressure-tight lid, and three rows of rod-shaped beaters—two driven and one stationary. Mixing action is intense: the drive unit for a 200-quart unit is a 10 horsepower motor. In making angel food cake, flour is charged to the mixer at the proper time from an auxiliary tank. Operating pressure is 5 to 22 p.s.i.g. A batch of angel food cake can reportedly be mixed in two and one-half minutes, and a batch of pound cake in one and one-half minutes. Superior aeration and better uniformity is reported. The batter is delivered to the depositors by plastic hose under mild air pressure.

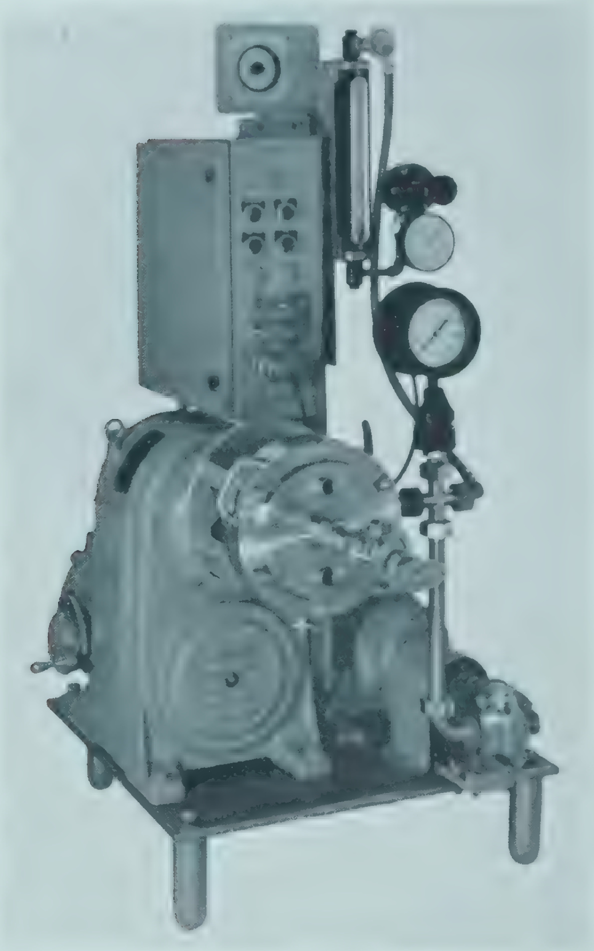
Continuous Mixers for Batters.—Semi-continuous mixing of cake batters was introduced in the U. S. in the mid 1940's. One of the first commercial continuous cake mixing systems was designed around a Votator scraped-surface principle. Another early system used a modified Oakes marshmallow mixer. In both systems the mixer operated continuously, but was fed from a premix prepared batchwise in standard batch cake mixing equipment. Later, approximately 1950, a truly continuous cake mixing plant was designed and installed using the AMF Oakes mixer, at the American Stores new Philadelphia bakery.

Currently (1960) there are at least four continuous cake mixers being offered commercially. They differ somewhat in design.

In the Votator scraped-surface principle, the mixer consists of one or more horizontal, stainless steel cylinders containing axially mounted beater bars which can be arranged to scrape the inner wall of the cylinder. An outer concentric cylinder is arranged so that a heat transfer fluid can be circulated through the annular space, to cool or heat as desired the batter being mixed. Mixing action is intense, and this machine also has the advantage of being operable under relatively high pressures—beneficial to production of highly aerated batters.

The Oakes Mixer (see Fig. 73) has a stainless steel exterior-mounted head, consisting of front and back stator halves and a rotor mounted inside. Teeth on either face of the rotor mesh with teeth on each stator. Premix batter is pumped in at the back center, is sheared repeatedly as it is forced out around the rotor and back to front center where is exits. Diameter of the rotor in the largest machine is 14 inches. Rotor speed is infinitely variable over a wide range. Production rate of the large machine is as high as 4000 lbs. per hour.

The AMF mixer is similar in external appearance to the Oakes, but the mixing head is quite different. Instead of splitting axially for dismantling,



Courtesy of E. T. Oakes Corp.

FIG. 73. SMALL CONTINUOUS CAKE MIXER WITH BATTER- AND AIR-METERING EQUIPMENT

the stator splits radially. The rotor has several rows of teeth on the periphery, which mesh with rows of teeth on the inside of the stator wall. Rotor speed is infinitely variable between limits, and as in the Oakes, a typical motor size for large units is 10/5 horsepower, high and low speed ranges.

These mixers are normally equipped with batter metering pump, air meter, and speed controls.

The intense liquid shear provided in mixing heads of this design is sufficient to emulsify air and shortening in the final mix, whereas conventional batch mixers require that some of the water be withheld while shortening is being creamed with dry ingredients and eggs.

However, the principal advantage lies in the unique ability to produce the highly aerated batters, angel food, sponge, etc., from a rough premix containing all of the ingredients—including flour. Air or inert gas is metered at a calculated rate, into the mixing head, along with a proportionate rate of premix. If it is desired to produce a foamed batter with a final specific gravity of 0.25, the proportion would be approximately three standard volumes of air to one of batter.

However, on angel food batter, the mixing head operates at up to 90 p.s.i.g., so that the air in the head, under compression, occupies a volume only one-sixth that at atmospheric pressure. As far as the mixing head is concerned then, the desired mixture is 1 part premix to $^1/_2$ part air, and this mixture is easily made, even with the flour present.

The dense foam so formed is delivered to the cake depositor through plastic or rubber tubing, of the correct length to reduce the pressure at the depositor to atmospheric. As the pressure is slowly reduced, the air bubbles in the foam grow in volume and the bubble walls get thinner. The end result is a very tender cake of unusually large volume. If a throttling valve is used to relieve pressure in the mixing head, the foam will be broken.

Sometimes an adjustable sanitary stainless steel device—designed to present a tortuous path to the exiting foam—is used to reduce the pressure gradually. This has the advantages of compactness and adjustability for different rates and batters.

The continuous cake mixers can be incorporated into completely continuous systems in cases where production schedules warrant (i.e., in the plant operating on a schedule of long, unbroken runs on a few cake varieties). A typical plant is that of the American Stores Company in Philadelphia. Fig. 64 shows the liquid, premixing and flour metering equipment located on the floor above the final mixing equipment.

Liquid ingredients, including plasticized shortening, are premixed in a vertical tank with high-speed propellor agitators. The resultant emulsion is metered to an open vortex type premixer to which the flour is fed from a gravimetric feeder. The premixer forms a rough premix which is metered to the continuous mixer with a stream of air. Operation is automatic and requires only one operator to produce up to 4000 lbs. per hour of batter.

In general, cake batter is much easier to handle as a liquid through pumps and pipe lines than is bread dough. The development of continuous mixing, automatic handling and depositing would be a much easier accomplishment for the cake plant than for the bread bakery. However, the economics of cake production is such that expenditure of additional development funds on the *mixing end of the plant* is not warranted.

Mechanization of the scaling, feeding and mixing operations in wholesale bakeries has reduced the cost of direct labor in that end of the plant to minor proportions. The new equipment, like any other heavy capital equipment, is expensive. But its productivity is high enough that the write-off costs are almost negligible in cents per pound of bread.

Innovations in mixing equipment design have come frequently enough in recent years to suggest that the technology of dough mixing is unlikely to go through a long static period like that of the 25 years prior to 1950. What additional changes are likely to occur?

Even with the impressive advances that have been made, the judgment of a human operator is still indispensable to the mixing of bread dough and cake batter. Control of the operation is "open-loop." A human operator must closely observe results and make corrections as necessary in operating conditions. There is no automatic quality detection and feed back control—techniques common to other industries. There are very few decision-making machines in the bakery.

However, in an industry as large as the baking industry, it seems likely that the next few years will see applications of these sophisticated techniques. It will be interesting to observe the changes that occur as ingenious machine makers attempt to obsolete even their latest inventions.

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CHAPTER 15

Fred D. Pfening

Fermentation and Proofing Rooms

Both fermentation and proofing rooms are essentially enclosed spaces dimensioned to accommodate a given number of troughs or racks and air-conditioned to provide favorable wet and dry bulb temperatures for dough fermentation.

Fermentation, *per se*, is the pivotal point in the production line. By this reaction, bread is given its essence for eating quality. But fermentation cannot stand apart from the mechanical processing complexities of bread in the individual bakery. The whole is but the sum of the separate parts and each part has its contributing influence on the whole. A failure in any one, and worse, in any two or more, subtracts from the potential optimum quality.

Mechanization and automation have decisively shaped the characteristics of baked products. The economic necessity for lowering unit cost, meeting competitive prices, and resisting inflationary trends is manifest, compelling yet more and more mechanization.

Where production and engineering ability are coordinated to create mechanically operating sequences, automation has the redeeming advantage of delivering physical uniformity. Timing is the key to automation. Since time and temperature are inseparable in dough processing, we must control temperature in order to control timing.

TECHNOLOGY OF AIR CONDITIONING FOR DOUGH PROCESSING

Air conditioning is the science of maintaining the atmospheric condition of an enclosed space at a predetermined temperature and humidity. The atmospheric conditions to be maintained are solely dependent on the use for which the enclosure is intended and are obtained by adjustment of temperature, humidity, and airflow.

In a fermentation room a favorable set of conditions is a temperature of 80°F. and a relative humidity of about 75 per cent; favorable conditions for pan-proofing are temperatures of 100° to 120°F. and about 82 per cent relative humidity. However, there are many contributing psychrometric factors and calculations involved in obtaining a perfect balance. Particularly for the novice or unspecialized engineer, the definitions and comments that follow should be most helpful.

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When a fermentation room atmosphere is cooled by use of chilled water pumped through a coil of tubing, the heat lost by the air is transferred to the chilled cooling water with a rise in the temperature of the water. Then this heat is again transferred by a condenser.

Condensers are used to liquefy a gas. A condenser for air-conditioning work consists of a large number of tubes inside a steel shell or cylinder. Water circulates inside the tubes while vapor (Freon 12) flows into the shell, circulates around outside the tubes, is *condensed* and drawn off as liquid. The heat accumulated by the water is tranferred to the vapor and after the vapor has been liquefied, it is passed through an expansion valve into vapor and again begins its cycle of transferring heat.

A Condensing Unit is an assembly attached to one base, and including refrigerating compressor, motor, condenser, receiver, and necessary accessories. The assembly is commonly called a compressor or condenser. Refrigeration compressors are used throughout the bakery wherever individual cooling purposes are served. Centrally located ammonia compressors are practically a thing of the past in bakery applications.

A British Thermal Unit commonly abbreviated B.t.u. is the unit of energy or heat required to raise the temperature of one pound of water one degree F. under standard pressure.

Flow of Heat

Walls transfer heat to the air in a fermentation room because they are warmer than the room air. Conversely, walls transfer heat to the air outside a proof box because the air inside is hotter than the air outside. Whatever this heat loss may be, the conditioning unit must replenish it. The flow of heat through a wall depends on three factors: the area of the wall; the difference in temperature of the spaces the wall separates; and the heat conducting properties of the wall. The same holds for doors, windows, roofs, floors, and all other surfaces with differentials in temperature.

Infiltration is the process of cold or hot air leaking into the enclosed air-conditioned space. The prime sources of detrimental air are bakery building doors, windows, elevator shafts, skylights, and ventilating fans. It is particularly unfortunate when an exhaust fan has been installed in a location which either blows air or draws air over a proof box. For every cubic foot of air exhausted from a bakery, a cubic foot of air must necessarily enter the bakery. We are concerned with the air which is cooler than the atmosphere of the proof box. The cold air that filters into a conditioned room or is blown at, or over, the structure, subtracts from its sensible and latent heat and must be restored at a rapid rate, if the proofing process is to be even reasonably maintained. This negative situation causes condensation, loss of heat, and moisture starvation.

Specific Heat is numerically the number of B.t.u. that must be transferred to or from each pound of substance to change its temperature one degree Fahrenheit. The specific heat of steel is 0.12; of dry air at 80° to 120°F., inclusive, is 0.24; and of dough is 0.88. Aside from the room structure itself, only steel, air, and dough, must be considered when the calculation is made to determine the air conditioning capacity required. It may be interesting at this point, to know that one cubic foot of air at 80°F. requires 0.01764 B.t.u. to warm it one degree; to raise air at 120° to 121°F. requires 0.01642 B.t.u. An explicit application of specific heat of critical interest to the production and maintenance departments, for very practical reasons, is that when a change-over is made in a proof box, from a four-strap pan set to a five-strap pan set, a 25 per cent increase in heat is required to compensate for the additional pan weight and dough piece weight. Cases sometimes occur where a proof box is purchased for 9- or 10-shelf proof racks for bread and later 17-shelf proof racks are purchased to be used with sweet goods, increasing the weight of the racks and the pan load. In addition, heavily laden sugar and shortening dough often requires more time and higher temperature for a satisfactory proof. The specific heat load of these extras calls for a next larger size heating unit. It would be unfair and unwise to blame the proof box manufacturer for

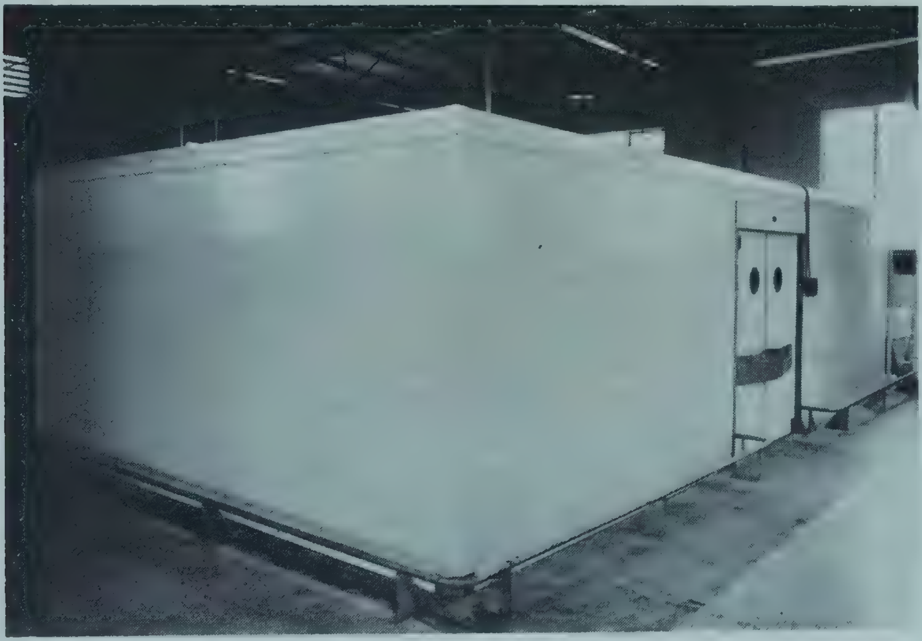

FIG. 74. PFENING MODEL 900 FERMENTATION ROOM WITH DOUBLE-ACTING, DOUBLE-SWINGING DOORS

the inadequate performance which may be observed unless he had been advised in writing of the proposed changes when the purchase was made.

Design Temperature is the temperature which a system is designed to (a) maintain or (b) establish under the most difficult anticipated conditions. When an air-conditioned system is to be designed, the temperature difference to be used in calculating the heat gains or losses through the surfaces must be determned. The temperature involved is dependent partially upon the geographical location of the proposed equipment. Usually this factor will apply only to a fermentation room rather than to a proof box.

Dry Bulb Temperature is a measure of sensible heat. The dry bulb temperature reveals only the intensity of heat and not the total amount of heat in the air. The total moisture air can hold is indicated by the dry bulb temperature.

Wet Bulb Temperature is the temperature of evaporation. To evaporate water at any temperature, latent heat must be supplied. When air is heated, the wet bulb temperature rises as does the dry bulb temperature. When the air is cooled, both the wet and dry bulb temperature fall, depending on how much heat is removed. The differential between the wet and dry bulb reading can be used to calculate the per cent relative humidity, *provided* the thermometers are accurate.

Wet Bulb Depression is the difference between the dry bulb and wet bulb temperatures under *identical* atmospheric conditions. For any given temperature, the greater the differential, the lower the relative humidity. Any condition which interferes with obtaining the lowest wet bulb depression is an extreme error in the design of air-conditioning equipment. A dirty wick, or dirty water, on a wet bulb thermostat, will give a false reading and atmospheric reaction. A motorized fan creating an air velocity of about 600 feet per minute over the wet wick, is necessary to yield accurate readings.

Dew Point Temperature is the dry bulb temperature at which the air in the proof box, or fermentation room, or elsewhere, becomes saturated with water vapor. When this saturation point is reached the vapor condenses as dew or particles of water.

Humidity is moisture or vapor present in the atmospheric air, or in any mixture of air and water vapor.

Relative Humidity is the percentage of moisture present in the air relative to that quantity which would completely saturate it at the existing temperature. Adding heat to the air lowers the relative humidity. When air with one grain of moisture per cubic foot is at 70° F., the relative humidity of this cubic foot of air is 15 per cent. It is a well-known fact that dough will "rise" or "proof" more rapidly and satisfactorily in the

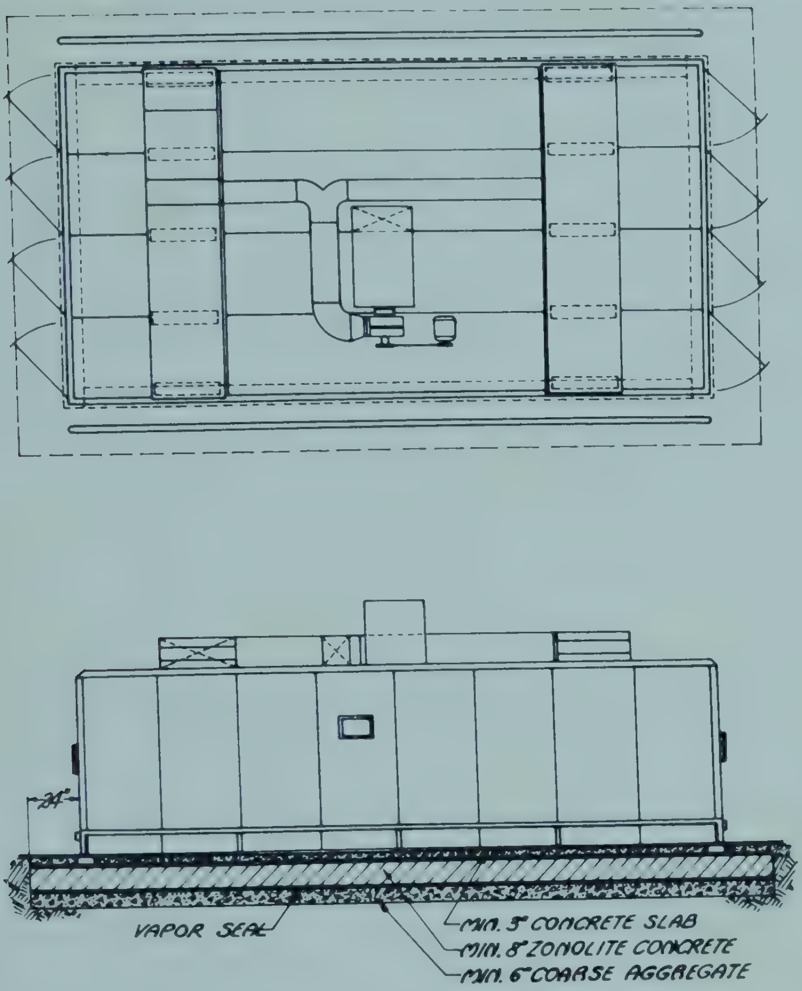

FIG. 75. CONSTRUCTION OF PROOFING ROOM FLOORS

presence of rather high humidity, and a favorable relative humidity range has been found to be from 72 to 83 per cent.

Latent Heat is the heat that must be added to cause a substance to change from solid to a liquid, or from a liquid to a vapor—but with no change in temperature. Moisture in the atmosphere exists in the form of superheated vapor. When the mixture of air and vapor is returned to the air-conditioning equipment, a certain amount of heat is removed from the superheated vapor in order to cool the air. In our operation we retain all the moisture possible and at the same time obtain sufficient cooling effect to maintain our dry bulb temperature. Therefore, the suction temperature of the refrigeration unit should be held high rather than low. The heat that is withdrawn causing the condensation of the moisture is equal to the *latent heat gain* of the conditioned room. In proofing and fermentation atmosphere, it is our purpose to lose as little moisture as possible and thereby save ourselves the task of reintroducing moisture to maintain predetermined relative humidity.

Sensible Heat is that heat which, when added or subtracted, results in a change of temperature.

Total Heat is the sum of sensible and latent heat.

Vapor

Where vapor is present care should be exercised in the design of installations since some insulations can absorb and retain destructive condensation inside walls and other structural spaces. Warmth and vapor can flow through asphalt, paper, plaster, and most building materials, including ordinary insulating material. Vapor condenses when the air reaches a dew point upon striking a colder surface. Vapor barriers should not be placed on both sides of all insulation. In a building the cold side should be able to "breathe." However, in a fermentation room we cannot always follow this rule because both sides may seasonally alternate as the "cold" side.

Air of higher outside temperatures will support more vapor than the cooler air inside a building. Often vapor flows from the outside to the inside, obedient to the law of physics that vapor travels from areas of greater to lesser density.

Vapor Barrier is material intended to prevent the passage of water vapor through a proof box or fermentation room wall so as to prevent condensation within the wall.

Saturation and Superheat.—The vapor or steam at the boiling temperature is called "saturated" and it remains saturated as long as any liquid is left. After all the liquid is changed to a vapor, any further heat added goes into heating the vapor and this raises the temperature of the vapor or "superheats" it. Thus, superheating the vapor means raising its temperature above the saturation temperature and the amount of heat necessary to do this is called the "superheat" in the vapor. It will be seen then that superheat is sensible heat.

Pressure and Temperature.—The temperature at which water boils depends upon the pressure on the water. The standard pressure is sea level where water boils at 212° F. If water is heated on a mountain top, say at 10,000 feet, it starts to boil when it gets to 193.5° F., because the pressure is less than at sea level.

Zero Gauge Pressure.—The pressure at sea level is zero on a pressure gauge. Pressures above zero are expressed in pounds per square inch and the pressure gauge is so graduated. However, pressures below zero are usually expressed in "inches of mercury vacuum," and the gauge is graduated in inches down to 30. A "perfect" vacuum is 29.92 inches of

Relative Humidity, per cent

	DRY BULB							
WET BULB	98	101	104	107	110	115	120	
88	67.5	60.1	53.5	47.6	42.4	34	28	
89	70.5	62.8	56.0	49.9	44.5			
90	73.5	65.5	58.5	52.2	46.6	37.5	31	
91	76.6	68.3	61.0	54.5	48.7			
92	79.7	71.2	63.6	56.9	50.9	41.5	34	
92.5	81.3	72.7	65.3	58.1	52.5			
93	82.9	74.1	66.3	59.4	53.2			
94	86.2	77.1	69.0	61.9	55.5	45.5	38	
95	89.5	80.2	72.0	64.5	57.9			
95.5	91.2	81.8	73.3	65.8	59.0			
96	92.9	82.3	75.0	67.1	60.2	50	41	
97	96.4	86.5	77.6	69.7	62.7			
98	100.0	89.8	80.7	72.5	65.2	54	45	
99		93.1	82.6	75.3	67.8			
100		96.5	86.8	78.2	70.4	59	49	
101		100.0	90.0	81.1	73.1	63.5		
102			93.3	84.1	75.8		53	
103			96.6	87.1	78.6			
104			100.0	90.2	81.5	68.5	58	
105				93.4	84.4			
108						79	67	
110						85	72	
112						91	77	
114						97	82	
116	Avoid using a Relative Humidity higher than 82% to prevent condensation within Box.						88	
118							94	

FIG. 76. CHART FOR CALCULATING RELATIVE HUMIDITY FROM WET BULB AND DRY BULB TEMPERATURES

mercury below zero (sea level) and the 29.92 inches of mercury are equivalent to 14.7 pounds per square inch, so one inch of vacuum on the gauge is approximately equivalent to one-half pound per square inch.

Absolute Pressure.—If we started our gauge scale at zero for a perfect vacuum, then sea level (or zero gauge) would be 14.7 pounds per square inch. When we refer to a zero that is a perfect vacuum, we call it "absolute zero;" if we refer to zero at sea level, we call it "zero gauge." In practical field work, we use the zero gauge almost entirely and, unless it is otherwise specified, pressure readings above zero gauge (above sea level) are meant.

Vapor Pressure is the equilibrium pressure of the vapor of a liquid in contact with the liquid. Vapor pressure is a factor in the condensation of moisture. The higher the dry bulb temperature at which the proof box is air-conditioned, the greater the flow of heat to and through the floor. With approximately 82 per cent of relative humidity at 110° F. dry bulb temperature the dew point is 103°. With a six degree differential, the condensation on a cold floor is considerable. For the continuous dough-mixing process, bakers are now calling for a three degree differential between wet and dry bulb temperatures, equalling 90 per cent relative humidity and a dew point of 107° F. with the dry bulb at 110° F. Under this situation the condensation rate can be terrific, unless adequate insulation is placed between the concrete, or tile, and the earth. Detailed instruction may be found under "Proof Box Floors" (p. 394).

Condensation is the opposite of evaporation; it is the process by which a substance changes from a gaseous to a liquid state. In a proof box, condensation or "sweating" is most likely to occur on the floor, ceiling, and walls inside the structure, because the dew point temperature is only slightly below the dry bulb or sensible heat temperature. When condensation occurs, it is caused by one or the other, or a combination of (a) insufficient insulation in the wall or ceiling panels, or under the floor; (b) cold drafts of air striking the panels or doors, originating from openings in the building such as windows, doors, elevator shafts, skylights, or ventilating fans; (c) operationally, the dry bulb temperature dropping while the wet bulb temperature remains constant per thermostatic setting. The latter is due chiefly to steam pressure dropping at the boiler; or from temporary diversion of steam to another piece of equipment, often the oven or a pan washer.

Condensation seldom forms on the fermentation room's inside wall ceiling, or floor because of the usual 80° F. dry bulb temperature. Although the 75 per cent relative humidity is high, the dry bulb is usually below the ambient temperature of the room. The fermentation room suffers more from excess exterior heat than from cold, except where a build-

		DRY BULB F.	98°	101°	104°	107°	110°
SPECIAL	3°	Wet Bulb degrees	95	98	101	104	107
		Relative Humidity per cent	89.5	90	90	90.2	90.4
		Dew Point degrees	95	98	101	104	107
		Grains Water per Cu. Ft. Air	17	18.6	20	22	24
Differential between Dry Bulb and Wet Bulb	4½	Wet Bulb degrees	93.5	96.5	99.5	102.5	105.5
		Relative Humidity per cent	84.5	85	85.2	85.6	86
		Dew Point degrees	93	96	99	102	105
		Grains Water per Cu. Ft. Air	16	17	19	21	23
	6	Wet Bulb degrees	92	95	98	101	104
		Relative Humidity per cent	79.7	80.2	80.7	81.1	81.5
		Dew Point degrees	93	94	97	100	103
		Grains Water per Cu. Ft. Air	15	16	18	20	21
	7½	Wet Bulb degrees	90.5	93.5	96.5	99.5	102.5
		Relative Humidity per cent	75	75.6	76.3	77	77.2
		Dew Point degrees	89	92	95	98	101.2
		Grains Water per Cu. Ft. Air	14	16	17	19	20
	9	Wet Bulb degrees	89	92	95	98	101
		Relative Humidity per cent	70.5	71.2	72	72.5	73.1
		Dew Point degrees	87	90	93	93	100
		Grains Water per Cu. Ft. Air	14	15	16	18	19
	10½	Wet Bulb degrees	87.5	90.5	93.5	96.5	99.5
		Relative Humidity per cent	66	67	67.7	68.4	69
		Dew Point degrees	85	88	91	94.3	97.3
		Grains Water per Cu. Ft. Air	13	14	16	17	19
SPECIAL	12	Wet Bulb degrees	86	89	92	95	98
		Relative Humidity per cent	62	63	64	64.5	65.2
		Dew Point degrees	83	86	89	92.4	95.6
		Grains Water per Cu. Ft. Air	12	13	14	15	17

Fig. 77. Psychrometric Chart for Determining Final Proof Conditions

ing wall with inadequate insulation forms a side of the room, consequently increasing the cooling load in warm weather and the heating load in cold weather. A proof box seldom suffers from exterior heat.

Transfer of Heat is necessary if we are to heat one substance by another. Heat can be transferred by conduction, convection, or radiation.

Conduction is the transfer of heat from one part of a body to another part of the same body; or from one body to another body in contact with it. To retard the flow of heat by conduction, insulation is required.

An empty space, as between two walls, is the best insulator against heat flow by conduction, but it does not prevent heat flow by radiation and convection. Of all heat transferred through structural spaces, about 50 per cent to 80 per cent is by radiation; all but about seven per cent of the rest is by convection.

Convection, which applies only to fluids (gases or vapor), is the transfer of heat from one point to another within the fluid by mixing of the one portion with another. In heat transmission, this meaning has been extended to include both forced and natural motion or circulation. One of the most important instances of convection air currents is in the natural ventilation of industrial buildings and other structures. In the bakery, an oven gives off heat by *radiation;* then air currents pick up this heat by *convection*, and thus warm the area a considerable distance beyond the source of radiated heat. We may simply describe convection as an air-wiping movement over a warm surface such as a radiator.

Radiation is the energy, that is, the heat, given off by a body, say a radiator, in the form of waves. One substance surrenders heat, and another receives it. To express it another way, radiation is the transmission through space of rays with the properties of light. Infra-red heat rays travel at the speed of light, are invisible, have no temperature, only energy. Radiated heat can be reflected from a bright surface. When absorbed by a surface, the rays are transformed to heat. The surface of any object warmer than absolute zero will radiate to a colder surface. Radiated heat can well become a source of trouble in bakery air-conditioning equipment since rays which are permitted to reach a dough piece in a proof box may cause overly rapid proofing of the dough. That is why the heating unit, distributing air ducts, and thermostats are isolated, or insulated, from the interior of a proof box; and the heat is carried and distributed uniformly throughout the box by forced convection air streams. However, the effect is not serious in a fermentation room because of lower atmospheric temperature and with heated air ducts suspended from the ceiling, while the doughs are close to the floor.

To temper a fermentation room easily, we must ward off unwanted heat rays, or radiation, as from an oven, or through a roof. Most heat

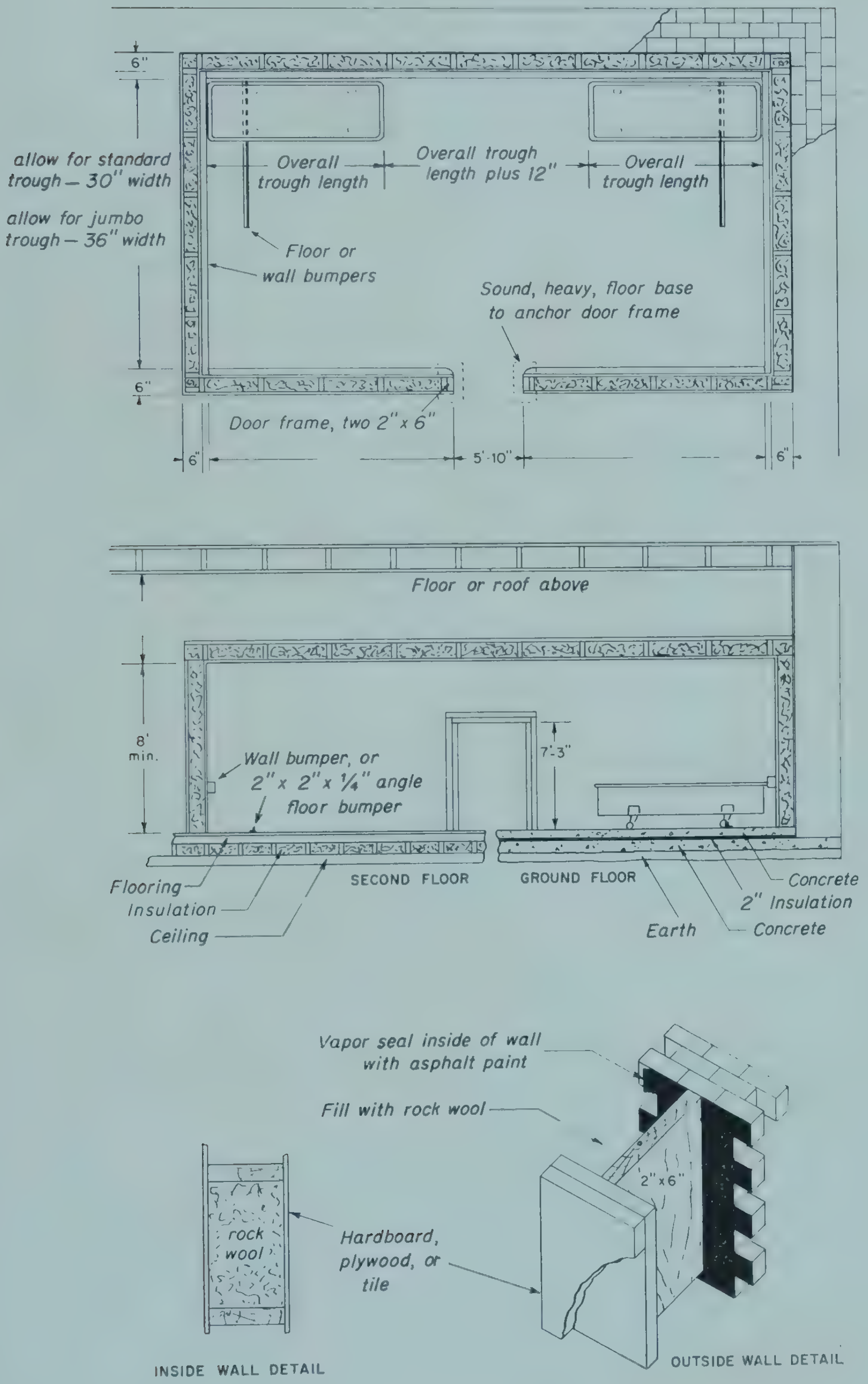
6"
allow for standard trough — 30" width
allow for jumbo trough — 36" width
Overall trough length
Overall trough length plus 12"
Overall trough length
Floor or wall bumpers
Sound, heavy, floor base to anchor door frame
6"
Door frame, two 2" x 6"
6"
5'-10"
6"
Floor or roof above
8' min.
Wall bumper, or 2" x 2" x ¼" angle floor bumper
7'-3"
Flooring
Insulation
Ceiling
SECOND FLOOR
GROUND FLOOR
Concrete
2" Insulation
Earth
Concrete
Vapor seal inside of wall with asphalt paint
Fill with rock wool
rock wool
Hardboard, plywood, or tile
2" x 6"
INSIDE WALL DETAIL
OUTSIDE WALL DETAIL

FIG. 78. DETAILS OF CONSTRUCTION OF PROOFING ROOM WALLS

flow through a roof space in summer is by radiation. There is no convection down, and little conduction through, low density air.

Temperatures can reach over 140° F. from the exterior in some bakery attics, and considerably more if oven radiated heat is present. A shield between equipment and sun, against radiant heat, lifts part of the load from cooling equipment and reduces installation and up-keep costs. But the building itself, which is perhaps not artificially cooled, needs an insulating shield.

In most cases, actual heat transfer is accomplished by more than one of the three possible means. Thus, a convector, or radiator, instantaneously heats adjacent air by conduction. The heated air rises and mixes with other air, thus heating by convection. Meanwhile, the surface of the device, or radiator, is emitting radiant energy and warming solids in front of it. Similarly with panel or radiant heating, the surface warmed by radiation immediately transfers heat by convection to adjacent air.

Insulation.—Thermal insulation is material used to effect a reduction of transmission of heat by a relatively large degree. The efficiency of insulation is measured by its "K" factor. This factor indicates how many B.t.u. per degree, per hour, will transfer through a piece of insulation one inch thick and one foot square. For instance, the "K" factor of corkboard is 0.34, foamglass 0.45, glass wool of 1.5 lb. density 0.27, rigid fiber board 0.33; "U" factor of common brick (four inches) is 0.81 while that of concrete block (eight inches) is 0.56.

Insulation has two points for discussion. We can insulate abundantly and thereby save much of the cost of heating and cooling a room. We can insulate meagerly, or not at all, and thereby increase the cost of heating or cooling a room. An additional difference between the two approaches is that it will also become more difficult, and costly, to temperature *control* an uninsulated room. All building materials have more or less insulating value and it is, therefore, a matter of selection and cost as to which is the most economical for the particular purpose. Insulation determines to a great extent what the dew point temperature will be under a given set of circumstances, and dew point determines at what dry bulb temperature condensation begins. The fact that both fermentation rooms and proof boxes are air conditioned for dough processing at comparatively high relative humidities calls for efficient insulation.

The closer the differential between wet bulb and dry bulb temperatures, particularly in proofing, the greater the liability becomes for changing the moisture-saturated air to water. No matter how much insulation has been incorporated into the wall and ceiling of the room, condensation can be brought about because the wet and dry bulb temperatures are controlled separately. As has been said elsewhere, if the steam supply

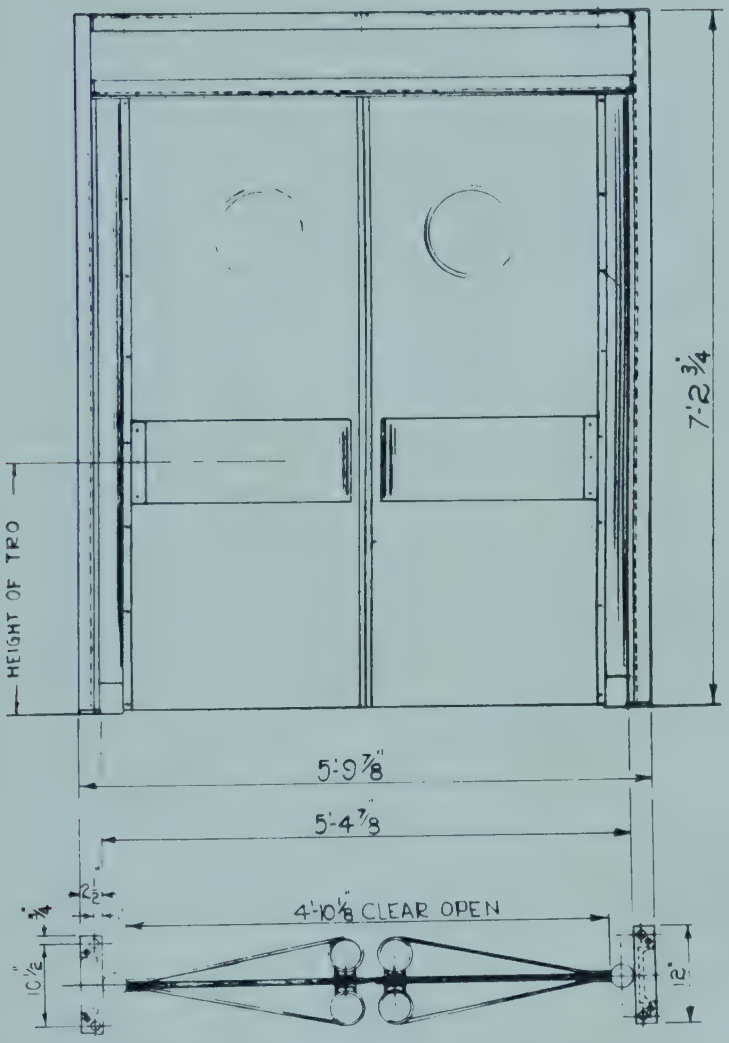

FIG. 79. DETAILS OF CONSTRUCTION OF PROOFING ROOM DOORS

fails to deliver a sufficient pressure and volume, the heat can go down while the humidity remains up, and the differential results in a dew point temperature and, therefore, condensation. Insulating material is relatively inexpensive considering its beneficial effect, and it should be used plentifully but not necessarily extravagantly. Each manufacturer of proof box equipment usually emphasizes that the baker is held responsible for maintaining compensating ambient temperature.

Many proof boxes and fermentation rooms are located on the ground floor level, where a concrete floor is laid directly on the earth. The earth temperature, under a concrete floor, is usually the temperature of water obtained in each locality at 30 to 60 feet below the earth's surface. This runs from 37°F. in the north to 77°F. in the southern tip of Florida. In either locality and all in between, floors laid on earth will rapidly condense the vapor which has been provided to maintain the desired relative humidity. The remedy is to insulate adequately under the floor, concrete slab, or other material. The insulation should extend at least 24 inches beyond the perimeter of the equipment itself, since concrete is a fairly good conductor of cold. A concrete bakery floor is continuous and, if the proof box floor is on the same level, "cold" will crawl, so to speak, through the concrete which is above the insulation and create a dew point temperature, resulting in condensation on the proof box floor and steel-covered panel walls of the proof box which make contact with the floor.

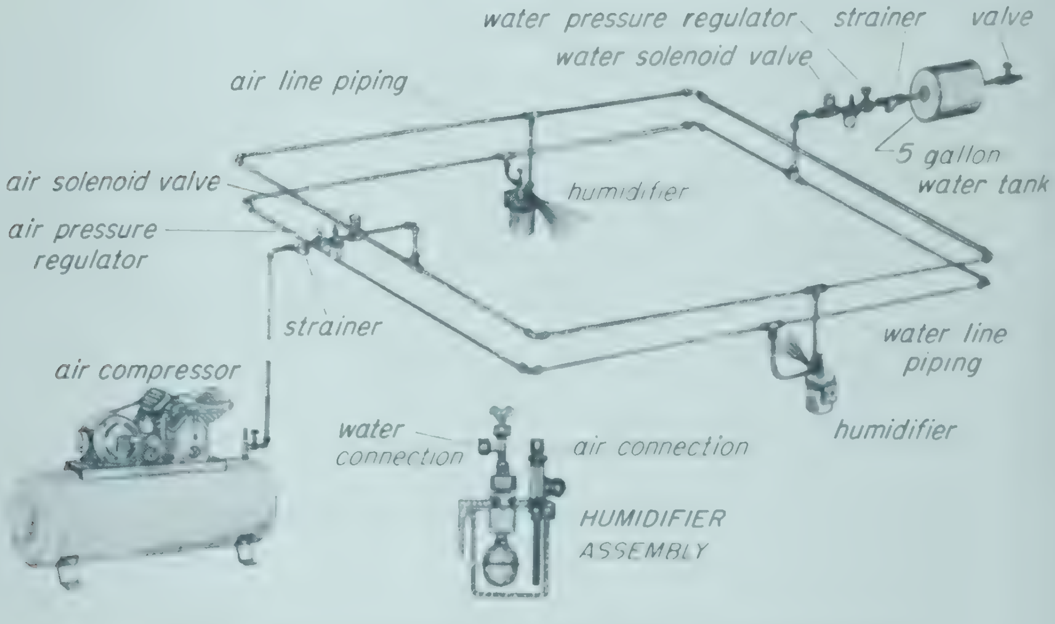
water pressure regulator
strainer
valve
water solenoid valve
air line piping
5 gallon water tank
air solenoid valve
humidifier
air pressure regulator
strainer
water line piping
air compressor
water connection
air connection
humidifier
HUMIDIFIER ASSEMBLY

FIG. 80. AIR CONDITIONING SYSTEM FOR A PROOFING ROOM

Geographical Weather Data

It is prudent for the design engineer to determine the weather statistics for a particular locality. Such data are available from published works on air conditioning. The weather bureau in any of the larger cities in the United States can supply answers to almost any pertinent question, from records going back 60 years or more. If an outside building wall is also the fermentation room wall or an insulated panel wall is in close approximation to the building wall, additional insulation is necessary. Normally, a design temperature of 0° F. minimum for heating, and 100° F. maximum for cooling, will catch all but a few abnormal days. The exceptions would be the extreme north of Canada for heating and the extreme south bordering the equator for cooling. In either of these instances, the task is not so much heating or cooling, but maintaining proper humidification when hot weather demands that the cooling equipment deliver its maximum. Cold, dry air infiltration has a tremendous thirst for moisture and is the nemesis for maintaining humidification. Likewise, in the hottest weather, with the cooling equipment working more constantly, the cooling coil may be wringing the water out of the room atmosphere faster than it can be inducted.

Sanitation

Sanitation for both proofing and fermentation rooms is covered by Sanitation Standards No. 10, approved July 1, 1955, by the Baking Industry Sanitation Standards Committee. Dough troughs are also covered as Standard No. 2, in the same publication. Neither the proofing nor the fermentation room has a *product zone*. The code provisions relate only to a *non-product zone* and the air-conditioning equipment. Copies are available at 25 cents per copy from the Committee Office, 511 Fifth Avenue, New York 17, New York.

PROOF BOX HEATING AND HUMIDIFICATION PREREQUISITES

The purpose of a proof box is primarily one of heating and humidifying to maintain wet and dry bulb temperatures which will cause a dough piece to proof within a scheduled time period. Many contributing factors influence performance success or failure. The process is essentially air-conditioning and subject to the vagaries of psychrometric deviation.

Heat Transfer

If a temperature control apparatus is to perform its assigned duty in a proof box, then sensible heat must be available. When steam pressure drops below 15 p.s.i.g., sufficient heat is not transferred from the heating coil or radiator to the recirculating air to maintain the desired dry bulb temperature. Normally, the humidification, or wet bulb control, continues to add moisture to the atmosphere resulting in an overly humidified atmosphere. Without protective circuity in the thermostatic complex to avoid a dew point, condensation will appear on cold surfaces. Steam pressure itself is not enough to supply the necessary sensible heat. Steam in volume is also required.

Pressure

Pressure of any fluid will be reflected regardless of the diameter of the conveying pipe. To obtain greater volume, a larger diameter pipe and pressure are required. A pound of water, when vaporized, will produce less than 1,000 B.t.u. If it takes up to 12,000 B.t.u. per hour to maintain 110°F. of heat per proof rack, pans, and dough, there will be twelve pounds of condensate draining from the radiator. A simple test is to collect the condensate for one hour, as it drains through the trap, and then weigh it.

The pressure of steam indicates its temperature; at 10 p.s.i.g. it is 240 degree, at 15 p.s.i.g. it is 250°F., and the higher the pressure, the higher the temperature. This is the reason why steam from a high pressure boiler must have a pressure reducer in the line and also why bare pipe should be provided for a distance of at least 25 feet to the proof box humidification unit to obtain *wet* steam.

Capacity

A proof box needs ample heating capacity to be drawn on for quick reaction to counteract infiltrated cold air. This occurs particularly when a door is opened to admit a cold rack, pans, and dough. Adding to this burden is the fact that with an open door the ambient air volume and temperature rush into the proof box at the lower part of the open door; and at the same instant, the conditioned atmosphere from inside the box rushes outward. Considering the number of doors involved and the rate of their opening and closing, we encounter quite a heat and humidity loss. The recovery rate is dependent on the sensitivity of the thermostat and the heat capacity of the conditioning equipment.

Gauges

Steam gauges are calibrated for *pounds per square inch gauge* which is universally abreviated as p.s.i.g. The pressure reading is no indication of the *volume* of steam available. Gauges do not remain constantly accurate. Inaccuracy is accelerated by steam surges overworking and shocking the mechanism. The shut-off valve between the pigtail and the gauge should be kept closed and should be opened only at the time a reading is taken.

Steam

A proof box does not consume steam continuously; the demand is intermittent and, for a great volume, is at short intervals. If a proof box were a totally closed space without air infiltration or ambient heat subtracting influences, wet- and dry-bulb temperatures could be maintained to fractional degree values. As it is, a proof box has many doors, many cracks, and many cold racks loaded with cold pans and cool dough entering and leaving only a few minutes apart. Steam of uniform quality is needed. The most common temperature failures derive from low pressure and low volume steam. Inadequate boiler capacity accounts for some of this, and even though the boiler has sufficient capacity for the proof box, the steam intended for it is suddenly diverted to an oven, a pan washer, or other equipment. A high pressure boiler with 60 p.s.i.g. has a steam temperature of 307°F. and at 75 p.s.i.g. a temperature of 320°F. When the pressure is reduced to 15 p.s.i.g. the temperature is not reduced proportionally.

Pressure Reducer

If the reducer is located close to the conditioning unit, the steam will be hot and dry, and when it is used for humidification it will add more to the dry bulb temperature of the atmosphere than to the wet bulb, thereby endangering the control of both. The pressure reducer should be located at least 25 feet from the conditioning unit, without insulation, so that lower temperature wet steam will be available for humidification; the temperature of this steam should not exceed 250°F.

Trouble has occurred in many instances because the reducing valve was old, rusted, or corroded, or the orifice was restricted. In other instances the reducing valve was too small to pass sufficient steam for heating and humidity requirements. A steam strainer is mandatory ahead of a reducing valve and for all automatic valves.

Condensation Leg Trap

A long steam supply pipe, from boiler to conditioning unit, should have a drip trap leg, located at the lowest sag point in the line, to remove the condensation slugs and prevent water from reaching the heating coil.

Radiator Trap

The steam trap can be a prolific source of trouble affecting the radiator output of heat to the point of extinction. The majority of troubles are in reality *system* deficiencies rather than bona fide trap troubles. To forestall troubles periodic inspection should be made. Trap effectiveness is very important in obtaining heating capacity. Two heat coils or radiators should not be connected into one trap.

Heat System Trouble Shooting

There are almost a dozen categories of trouble in connection with a steam trap and its system connections. The following are the most important problems and their causes:

No Heat.—(a) Low steam pressure; (b) apparent pressure, but no volume of steam; (c) excessive pressure; (d) supply line filled with condensate; (e) insufficient steam volume because of small supply pipe (f) back pressure. (g) return pipe too small to carry away all condensate (h) dirty trap; (i) defective trap. (j) worn parts or worn seat. See below

No Flow of Condensate.—(a) Steam pressure too high (check limit pressure on trap); (b) pressure regulating valve out of order; (c) pressure gauge on boiler reads too low; (d) steam strainer in supply line stopped; (e) steam supply volume robbed by oven, etc.; (f) no air velocity through heating coils; (g) steam valve fails to open; or (h) thermostat or relay failure.

No Water Coming to Trap.—Pipe line or elbow plugged with dirt. Same causes stated in the two preceding paragraphs may lead to this trouble.

Continuous Flow of Condensate.—(a) Abnormal water condition; (b) boiler may foam or prime, throwing large quantities of water into steam lines; or (c) abnormal condensation taking place in feed steam line due to exposed pipe in cold location. Such conditions will prevent heating coil from producing rated capacity.

Steam Loss.—(a) Valve fails to seat; (b) piece of scale or pipe cutting lodged in orifice; (c) worn seat; or (d) trap thermostat needs replacing.

Sluggish Heating.—(a) Other units or traps of larger capacity emptying into same return line may cause intermittent back pressure on the trap in question; (b) water slugs in supply line (remedy: install a large capacity trap in the supply pipe at lowest level of pipe); (c) vacuum in return line; or (d) air bound.

Mysterious Trouble.—(a) Back pressure may reduce capacity of trap; (b) return line too small; (c) vent in return line may be plugged; (d) obstruction in return line; or (e) other traps may be blowing steam.

Imaginary Trouble.—If it appears that steam escapes every time trap discharges, remember: Hot condensate forms FLASH steam when releasing to lower pressure. Flash steam will usually condense quickly in the return line. A real steam leak under pressure appears bluish.

Fact.—A proof box operating at 110° F. will require a minimum capacity of twelve pounds of steam per proof rack, per hour. If low heat or low humidity occurs, first provide sufficient steam capacity, but not above the trap pressure limit.

IMPORTANCE OF PROOFING ROOM FLOORS

All floor areas on which the structure is to rest should be of equal elevation, particularly the perimeter where the major portion of the load is carried. The elevation points should be established by a transit level. A sound floor must be provided under the proof box. The floor must not only support the structure, but also must have sufficient insulation and moisture-excluding qualities to prevent a constantly wet floor surface. Water vapor which condenses is lost and, necessarily, must be replaced. Laying new floor, rather than the use of a doubtful old floor, is advisable when a new proof box is to be installed, or when an old box is moved to a new location.

Floors laid directly on the earth will rapidly condense overlying vapor to water. The remedy is to insulate properly the floor area under, and for 2 to 3 feet beyond, the perimeter of the proof box. The higher the dry bulb temperature at which an air-conditioned enclosure is operated, carrying approximately 82 per cent relative humidity, the greater the flow of heat to and through the concrete floor. The condensation potential under such conditions is great. Insulate as the manufacturer recommends, not only to prevent condensation, but also to prevent the loss of heat. Where proofing temperatures are up to 120°F., we suggest that heat conductors be installed under the floor surface to maintain a floor temperature of 112°F.

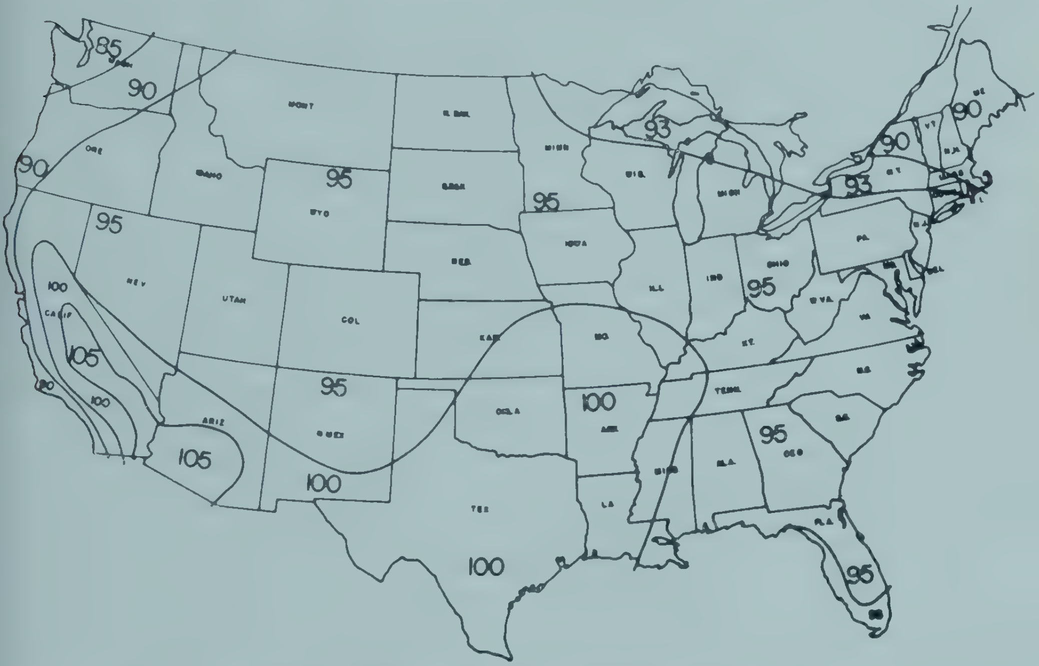

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FIG. 81. MAP OF OUTSIDE DESIGN DRY BULB TEMPERATURES FOR COOLING ESTIMATES

The ideal proof box floor has: (1) a tile surface to take the wear of caster mounted racks, and provide the utmost in sanitation; (2) a surface slab of solid concrete or slab used as a sub-base for tile, should be a minimum of three inches thick in order for the lag screws to have secure anchorage; (3) under this slab a Zonolite insulating concrete of not less than eight inches depth and extending 24 inches beyond the outline dimension of the proof box, on all four sides. This should be a 1 to 6 mix being 1 bag of cement and 1½ bags of Zonolite stabilized concrete aggregate; (4) if proof box is less than ten feet away from an outside building wall, the wall and floor should be separated with 12-inch width and 8-inch to 12-inch depth of Zonolite insulating concrete to prevent "crawl" of cold to the floor and wall panels of the box. If the box is close to a cold wall, the separation strip is a positive "must."

Where the soil on which the concrete is to be laid has recently been disturbed and there is danger of settling, a reinforcing steel mesh should be placed in the concrete. Where the slab is below grade, in a poorly drained location, or where there is a high water table, the soil should be stabilized by raking dry cement into the top inch of soil, sprinkling

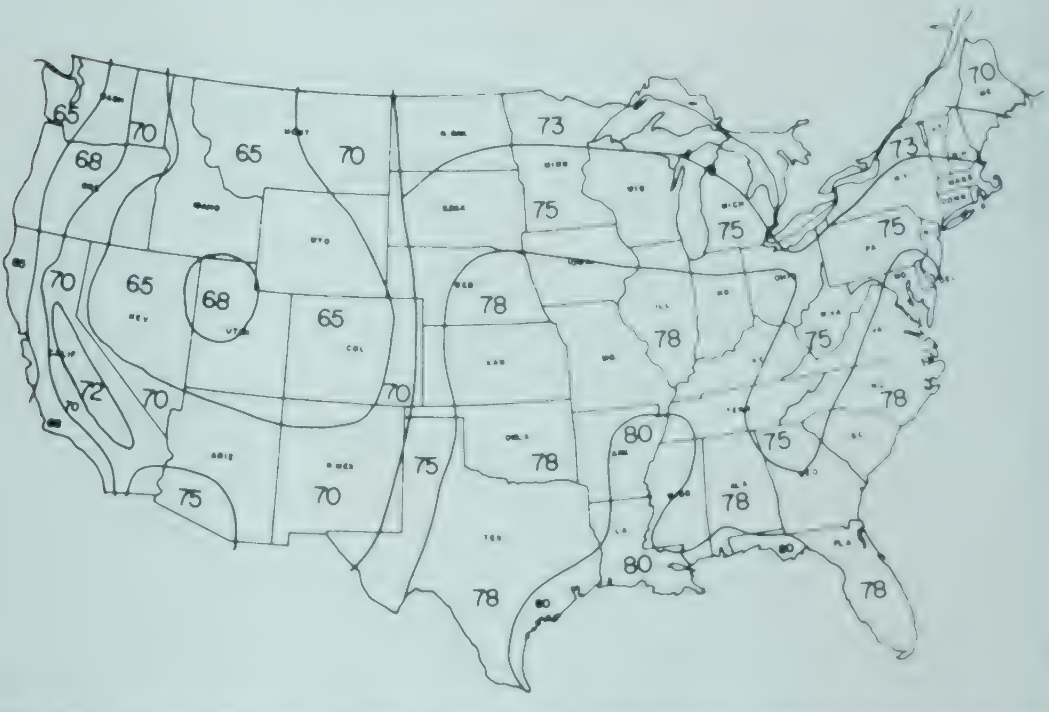

FIG. 82. MAP OF OUTSIDE DESIGN WET BULB TEMPERATURES IN THE UNITED STATES

it with water, and rolling it to a hard crust. Over this, mop down two layers of water-proof paper with hot asphalt. This membrane should be turned up against the outside wall to the height of the concrete.

When the slab goes over a well-drained area, the insulation would probably remain drier if no vapor-seal membrane is installed. When the proof box temperature is 110° F. dry bulb and 104° F. wet bulb, and the earth temperature is approximately 55° F., the tendency is for the moisture to go toward the earth. It is, therefore, important to ascertain the moisture condition, or probability of what will occur, in order to decide whether or not to use a vapor-seal membrane between the earth and the insulation. This phenomenon is true regardless of what type of insulation is used. A vegetable material insulation will in time decay. It should be remembered that a wet insulation material loses its insulating quality.

TYPES OF PROOFERS

The terminology of proofing should be established to differentiate between conditions existing before the piece of dough goes to the molder and after it leaves the molder. When dough is delivered from a divider it has a raw surface with the gas practically eliminated from the cells. Then the dough piece is placed in a rounder where it is dusted and spirally rolled until a skin is formed. From the rounder the piece is deposited on a belt, shelf, or pocket of an *intermediate* proofer, where it remains 5 to 15 minutes, and sometimes longer, continuing its fermentation so that it becomes pliable and formable and can be rolled into a flat sheet by the rolls of the molder, curled like a jelly roll, and compressed to a shape, length, and diameter to fit into a baking pan. The panned dough now goes into its final proofing stage, in a *final* proofer; more commonly called a proof box.

Final Proofing

By the time the flat shallow box was abandoned and the first total enclosure came into use, the traditional "box" continued as an accepted designation in the bakery field; old-time bakers always called such a room a "steam box" and many still do. In those early days only unconfined steam was utilized for both heating and humidification. When the writer was a comparatively young man, he designed an "improved steam box" by sinking a pit under the box and laying steel channels on a level with the bakery floor for track to support castered proof-racks. A perforated steam pipe was placed near the bottom of the water-filled pit with a valve handily located to regulate the temperature, as best could be. But, since excess humidification was not necessarily an evil in those days, this "new idea" was an improvement written up by the trade journals and many of these steam boxes were built all over the country. As one may imagine, after several days use, the odor from the water became somewhat obnoxious.

The name "proof box" came out of tradition; the purpose being to consummate "final proof." Intermediate proof is the first act; final proof the second act. There have been many types of semi-automatic final proofers. Now with fully automatic proofers, they too, will persistently be called proof boxes.

Floor Type Proof Box

The floor-type proof box employs caster-mounted proof racks, with 9 or 10 shelves, 24 or 28 inches wide, on which the pan straps are placed and then moved into the "box" for the final proof. Seventeen-shelf racks are also used for buns and sweet goods. The modern version of the proof box structure is a steel frame, covered with insulated panels, with doors at each end, for each lane, through which the racks move periodically at a rate to consume the previously determined proofing time; from 50 minutes to as long as two hours. The air-conditioning system is automatic, although the handling of the proof rack is manual.

Overhead Rail Final Proof Box

The overhead rail or Monorail type of proof box is similar to the floor type except that it is built higher to accommodate the rail and trolley-mounted proof racks. These racks are also manually moved about. A mechanized method for moving racks has been developed, but is not widely used. The same air-conditioning system, as on the floor type, is used.

Traveling Final Proofer

A proofing tunnel with conveying means similar to the traveling hearth oven was first used many years ago. In the beginning it also was supplied only with unconfined steam for heat and humidity; and was manually adjusted for temperature and humidity. Automatically controlled air-conditioning systems are now used for proofers of this ancient type.

Other traveling hearth or belt-conveying types have been built and have given moderately satisfactory performance. However, large floor space is required since the entrance end, being so far from the delivery end, may cause the make-up area to be as much as 200 feet away.

Totally Automatic Traveling Final Proofer

The development of a fully automatic conveying system for proofing was motivated by its potential economic value in the production line. Its profitable use has grown as the baking industry increased its dough pounds per hour oven capacity. The latter progress grew out of several important modernization changes in production equipment and methods. Make-up equipment from divider to molder has improved so that high-speed delivery of dough pieces is attained. Probably the greatest influence has been the newly developed practice of shortening the oven-bake period to as little as seventeen minutes. Admittedly, the practice is controversial within the industry and discussion continues on the relative merits of the "slow bake" and the "quick bake."

Floor space and ceiling height in a modern sanitary bakery building are costly. Equipment has an annual cost per square foot occupied. Suspended tray and wire belt conveying types are waived in favor of rack type or stabilized tray type because less floor area is demanded. Of course, only large production bakeries are justified in making the investment which is required.

The caster-mounted rack has been standard for years; the older members of the trade will recall the wooden rack and trough, and their successors, the gradually improved steel rack and trough. Today, the automatic multiple-tier proof box necessitates a new design in trays and racks; one that has a length of shelf to load fully the width of a modern oven mouth at one full sweep of the pusher-arm.

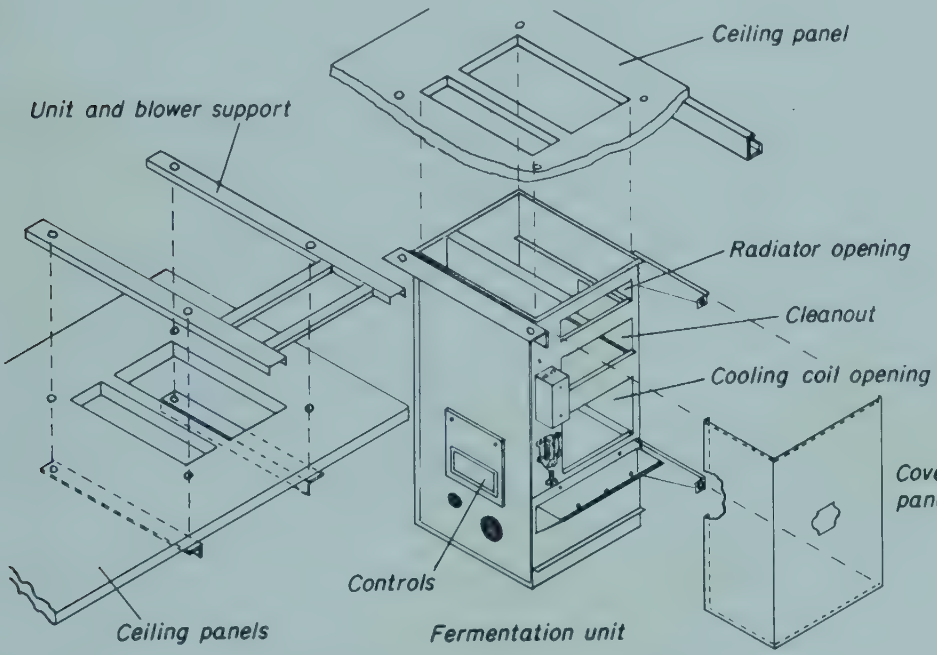

FIG. 83. FERMENTATION ROOM CONDITIONING UNIT

To obtain adequate proofing time and dough weight capacity, the overall dimensions change in length or height, or both, proportionally to the hourly production rate. The height and length, therefore, are dictated by the overall dimension of the tray or rack, which in turn is governed by the length, width, and number of trays or shelves to the rack. The less shelves to the rack, the more racks required. The greater the number of shelves per rack, the greater the height of the whole structure. This, in turn, requires that the building ceiling height be adequate, or else a pit must be sunk in the floor to compensate for a low ceiling. In fact, from a design standpoint, it is desirable to have a pit since it facilitates the loading and unloading of the strapped pan from the molder-panner to the rack shelves, and from the rack shelves into the oven. Moreover with a pit of adequate depth, favorable space is provided for efficient distribution and recirculation of conditioned air. A "pit" as designated here means an area equal to the length and breadth of the proofer housing; it may be as much as 40 inches deep. Adequate drainage is mandatory.

The overall weight of a completely automatic rack-type proofer, for 4,000 to 6,000 lbs. per hour, may be 35 tons or more. A structural engineer should, therefore, be employed to make a survey of the premises to determine the load carrying capacity of an existing building, or the need for an additional foundation load capacity to carry safely the perimeter concentrated load. In the event of a pit, the wall itself, or the floor of the pit, would carry the entire load. The concentration points of the load would be distributed at the location of the vertical steel supporting members.

The travel of the rack is intermittent, and the proof time is adjusted by loading a greater or lesser number of shelves per rack, or by adjusting the time required for the loading and unloading of each shelf. It is highly probable that each installation will require special and individual work by the design engineer to accommodate the specific oven bake rate and the proof time required.

Mechanized rack conveying, necessarily intermittent, should be without excessive vibration, shock or start-and-stop impact. As the dough piece continues to proof, the gas generation and retention render the cell structure less stable for self-support. Cell structure collapse has a negative effect on the quality of the finished loaf. Certainly in "balloon"-proofed bread, any shock at the maximum proof state could be destructive.

Air conditioning for mechanized trays or racks is identical, in principle, with that required by the floor caster rack-type, with ductwork alterations. Temperature levels are easier to hold on the automatic traveling type since the several door openings on the floor proof box are eliminated. However, with a standard floor proof box, the proofing may be observed and a rack pulled as required. Several bread varieties, including sweet goods, may be proofing at the same time and each kind pulled when sufficiently proofed, or when the oven is coordinated for loading.

The extra heavy racks used in automatic proofing units demand heavier supporting steel members, and in a single or double-deck design a tonnage mass of steel having a specific heat of 0.12 is heated to within a range of 110° to 120° F. The closed proofing room has minimum openings for infiltration of outside air and it cannot be cooled rapidly, if at all, without elaborate cooling means. Also, there is a large proofing area with extended pan capacity. When switching bread types or proof time, and possibly also when making a temperature change, this mass of steel cannot lose its stored heat in time to prevent a delay in production operation. This indicates the necessity of adding cooling to heating and humidification, but raises doubts as to its feasibility.

Air conditioning for automatic proofing does then take on the character of a fermentation room system-heating, *cooling*, and humidification being required. Fermentation room atmosphere is automatically held at fixed wet bulb of 74° and dry bulb of 80°F. temperatures constantly, with only the wet bulb setting optionally changed in some instances. The highest proofing temperature, at least up to this time, is 120°F.—a 40 degree elevation above normal bakery ambient temperature. Lower dry bulb temperatures for different products or to take care of emergencies appear desirable and, in exceptional cases, absolutely necessary. As atmospheric dry bulb temperature declines, the capacity of the atmosphere to hold water also declines. Under this circumstance the moisture, relative to the heat, may become so high that a dew point temperature is reached, resulting in the steel, pans, and dough piece being lightly covered with free water. This situation is further aggravated where a cooling system is incorporated to accelerate the temperature reduction—particularly where a direct expansion cooler or chilled water are used rather than the spray washer method of cooling.

Difficulties occur where the cooling coil is located ahead of the heating coil (radiator), in the same unit housing. A proofing room may have a 40 degree difference between inside and outside temperatures. However, the cooling coil with water medium at 35°F. or direct expansion medium at a lower temperature, may be cooling the air to about the same temperature. The heating coil has probably been operating continuously at a face temperature from 220°F. and upwards. This cooled air at high velocity is passing through the heat expanded finned tubes of the heating coil. At this moment there is a rapid contraction of the finned tube, causing it to pull itself from the coil headers, resulting in a damaged connection. There may be two effects of this damage: First, leakage of steam or water into the air stream, thereby boosting the humidification and interrupting the control of the wet bulb thermostat; second, creation of a vacuum within the heating coil, which further aids the destruction of the finned tube connection. For superior performance in maintaining dry bulb temperature in the atmosphere, the heating coil should be supplied with a continuous flow of steam to furnish 80 per cent of the atmosphere's heat requirement. The other 20 per cent is maintained by the "off" and "on" operation of the steam supply valve at the call of the dry bulb thermostat. Under this favorable plan of heat leveling, the chilled air from an adjacent cooling coil would be operating against a continuous heat output from a hot heat coil. Parenthetically, it should be indicated that the cooling coil and heating coil in a fermentation room conditioning unit perform adequately when the two are twelve inches, or more, apart, because dry bulb temperature is only 80° F. and in a well insulated room little heat loss occurs.

Separate conditioning units should be provided for more ideal performance—one for cooling, the other for heating. Two blowers may be used, or one blower with a damper switching arrangement, to channel the air to whichever unit requires it.

The simplest method for quickly removing sensible heat from an enclosure is to locate a sufficiently large exhaust fan in an opening in one end of the room and an adequately sized free opening in the wall at the opposite end. To apply the principle to a proofing enclosure with a temperature of 110° to 120°, the incoming air is channeled through a "spray washer" to eliminate foreign particles and obtain evaporative cooling. The extent to which the incoming air is cooled is dependent on the outside wet bulb temperature, the number of spray banks, and the number of gallons of water per minute per spray bank. The efficiency for one bank is 65 per cent, two banks 80 per cent, and three banks 90 per cent. The air washing principle is used in many different applications. In dry atmospheric areas of the country, air washers for evaporative cooling easily provide low degree results. On the contrary, the high humidity areas such as Miami, New Orleans, and Washington, D. C., require superior design talent to obtain acceptable temperature reduction by evaporative coolers.

Passing air through a washer will saturate the effluent air at the entering wet bulb temperature; there is no change in total heat of the air. Within the air washer there is an exchange of heat between sensible heat and latent heat. Air leaving the air washer at lower temperatures sweeps through the duct system into the heated space of the final proofer and picks up the heat rapidly, thereby lowering the space temperature. The relative humidity of the space will only be slightly affected because of the volume of the internal space heat to be absorbed. In this application temperature would be lowered by convection if there were no air washer; the mere volume of air would act as a simple ventilating system. The air supply in a duct passing through a warm area will pick up heat before reaching the heated space. Under some conditions condensation will result and insulation is indicated. High air duct velocities will assist in keeping temperature losses at a minimum.

A washer is required to free the air from dust and foreign particles

The air stack, through which the outside air is brought in, requires a screen at the top opening to prevent birds and insects from being sucked into the washer.

Use of air-cooling facilities in a final proofing enclosure has not had sufficient time to establish its value. Several cooling installations have been made principally for changing temperature as rapidly as possible when an emergency "shut down" in production occurs. In addition, the washed air method appears to be the most effective method of any likely to be used for cooling proof rooms. One automatic traveling final proofer has been cooled by the direct expansion method, i.e., via a refrigeration compressor and its components. However, insufficient time has elapsed to prove its feasibility.

There are pertinent questions that should be asked: (1) To what degree should cooling extend? (2) How effective is cooling in obtaining beneficial results? (3) Are the results obtained, if any, worth the cost? (4) With two categories of cooling to choose from, should the proofing rate be "arrested" totally or merely "retarded"? This application is akin to that of a "dough holding room" where dough is to be held in an "arrested" condition over a week end, beginning with a temperature of 80°F. and bringing it down to 45°F. a reduction of 35°F. In this instance, there would be a considerable number of troughs of dough and, instead of 8,000 lbs. of dough to contend with as in a final proofer, the holding room may have 80,000 lbs. of dough. There exists some experience in this field and, when related to the final proofer, serious doubt has been expressed as to the possibility of finding a favorable solution for proofing rooms. Of course, some intermediate aid may be possible.

To arrest fermentation in a given size dough piece, involves bringing the interior of the dough piece to temperature at which yeast cells are almost inactive. Yeast is held in storage between 40° and 50°F. and exhibits very little activity at these temperatures. It therefore follows that the dough piece in process of proofing, initially in an atmosphere at a temperature of as much as 120°F., must be brought down to a temperature of 45°F. at the center of the dough piece, a drop of 70 degrees. This phase alone presents a stupendous problem of cooling. However, this is only one aspect of the problem since the reduction must be accomplished in a limited period of time, say not longer than 15 minutes. Making a sample calculation based on a dough load of 8,000 lbs., a temperature differential of 75 degrees, and specific heat of dough at 0.88, a requirement of 44 tons of refrigeration *per hour* is found. To accomplish the necessary cooling to "arrest" fermentation within 15 minutes, we need four times the foregoing capacity or 176 tons. This is for the temperature reduction of the dough *only*. There remain the pans, racks, all of the steel and the atmosphere to cool. From a cost and operational standpoint it would appear that "arresting" proofing is totally out of the question. In any event, the application is of theoretical benefit only, when an emergency arises and the dough is held in the proofer for an indeterminate period of time until repairs were made and then the proofing continued.

The "retarding" of the proofing rate, by reduction of temperature, when a change in product type and proofing time is desirable, is possibly a more practical and effective process, yet doubtful. Supposing a run of one type of dough at a temperature of 120 F. for a 70 minute proofing period has been completed and the next run of product is to be at 100 F., a reduction of only 20 degrees is required. Obviously, the reduction temperature and period should be equal to the product change-over time interval, say ten minutes.

Again calculating on the basis of the dough weight then in the proofer and not considering the other factors such as steel and atmosphere, the refrigeration load would be but twelve tons if the cooling were to be accomplished in one hour. However, the ten minute period is six times faster, so there is need for 72 tons of refrigeration *for the dough only.*

The only reason for elevated proofing temperature is to shorten proofing time. It has been stated that 60 per cent of the total fermentation takes place in the proof box and if this is true it should direct attention to the several facets of final proof performance, particularly as related to high-speed automated equipment. For several years, a dry bulb temperature of 98 F. was accepted and practiced; then a transition period (which is still in effect) occurred when steps from 98 to 110 F. became popular, and now we have several ranges up to and including 120 F. Each higher step brought its own special problem, just as higher output equipment brought technical problems. Whatever the problems may be, we cannot quarrel with economic and technical progress, which appear inevitable anyway. However we have equipment of *today* with which to contend.

From the foregoing it would appear conclusively that the time required for effective cooling eliminates its application. First, the seeming improbability, if not impossibility, of providing sufficient heat transfer by refrigeration for indeterminate periods when emergency "down time" occurs in production and when a power failure halts all mechanical operation—including refrigeration. Second, it would also seem difficult to obtain sufficient cooling to lower materially temperature between runs of different types of dough; the time factor alone eliminates the opportunity for beneficially reducing temperature.

Automatic proofers and ovens should be equipped with stand-by hand or mechanical auxiliary power (e.g., a gasoline engine) to operate them in case of power failure. The auxiliary power supply may not permit ideal operation but, at least, the dough in both the oven and proofer could be saved. It is no small saving of labor and cost to avoid cleaning dough from pans.

Since it is more feasible to heat air gradually than to transfer heat rapidly by refrigeration to cooler temperature, it is desirable, where production permits, to run the doughs requiring lower proofing temperatures first and then to progressively raise the temperature and schedule other type doughs accordingly.

Proof Box Operating Instructions

Start-up.—Have operating steam pressure near 15 p.s.i.g. Turn on blower and master control switches. Maintain bakery at 75° F. minimum. Avoid cold drafts over box; close doors quickly. Use humidity cutout switch when preheating.

Preheating.—Allow 30 minutes minimum to warm steel, panels and floor. Obviously, a cold bakery will cause more time to be required for preheating the proof box than will a warm bakery.

Rack Loading Method.—Enter racks across box. Repeat, moving previous rack forward one length only. Uniform proofing will not be obtained otherwise. Do not load one lane full at a time in boxes over one rack deep. (This paragraph does not apply to automatic types.)

Maintenance.—(1) Maintain uniform steam pressure at 15 p.s.i.g. Adjust by-pass valve at DB heat valve to radiator and leave open at all times to keep radiator hot, and to carry major steam supply, leaving automatic valve for top-level control. (2) Clean steam strainer monthly. (3) Keep unit lid and cleanout slides tightly closed. (4) Avoid leaving doors open unnecessarily. (5) Avoid cold drafts from doors, windows, skylights, or fans, striking the proof box. (6) See manufacturer's Instruction Manual for servicing steam valves, traps, wet bulb fan motor, relays, and thermostats. (7) Oil door hinges monthly. (8) Clean unit sump, radiator fins, strainers, traps, monthly. (9) Install a clean wick on wet bulb thermostat every 48 hours of operation; clean well thoroughly; keep wick fully up on bulb. (10) Consult manual on operating parts and assemblies first—then, write in detail to factory direct, if further information is required. Have the manual at hand for quick reference.

Temperature Control Apparatus

Control.—The word "control" has broad meaning; "direct, master, dominate, subdue, restrain, check, curb, moderate, repress, guide, regulate, coerce, manage, and govern." Apparently, we may use the word in a very broad sense. In this particular case it means raising or lowering temperature, raising or lowering humidity, and directing the distribution of air to obtain a desired atmospheric environment favorable to dough processing. The human body is a complicated mechanism and nature has implanted a control which will adjust a heat balance through a wide range of external conditions. When the external atmospheric conditions rise above the body surface temperature, the body heat loss is restricted, and the body sweat glands then go into action to maintain the heat balance by evaporation of perspiration. As long as the evaporation and resultant latent heat loss are adequate to maintain the heat balance, the body will "control" normally.

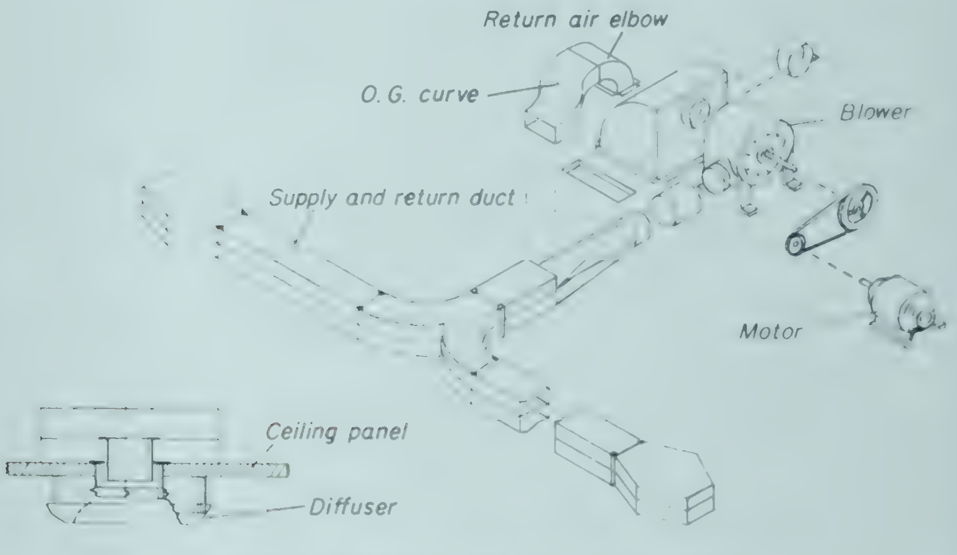

Fig. 84. Fermentation Room Ductwork

The proof box control equipment is analogous only to the extent that the human body and a proof box are enclosed; both are affected by external conditions. Atmospheric temperature cannot be controlled except within an enclosed space. The type of construction enclosing the space is, in itself, a controlling temperature factor. Design and construction must include control instrumentation in order to gain the temperature reactions desired. A correct interpretation of the psychrometric chart reveals the reactions the control must regulate.

Instrumentation.—A thin column of mercury enclosed in glass is a thermometer. Insert wire contact into the bore of the thermometer and it becomes a temperature sensitive switch, reacting when the mercury rises or falls. A low milliamp current passing through the mercury causes a relay to open or close, and this relay furnishes the larger amounts of current required to open or close a valve or other control units. Other thermostats utilize sensing elements made of two substances having different coefficients of expansions. Changes in temperature cause movement of the element as a result of the differences in the extent of expansion or contraction of the two substances.

A humidostat is an apparatus for obtaining a reaction from changes in the moisture content by hygroscopic substances such as paper, wood, skin, or human hair, which stretch when wet and contract when dry. The moisture content of the atmosphere governs the extent of stretch or contraction, and energizes a relay at the per cent of relative humidity desired. A humidostat is not as reliable or accurate as a wet bulb mercury thermostat with a wick on its bulb, from which air evaporates water to an extent dependent on the concentration of water vapor in the atmosphere. Mercury contracting thermostats are extremely sensitive and may be provided with multiple contacts and calibration by degrees.

Wet and Dry Bulb Thermostats are physically alike except that the calibrations of the degree marks are different. The degree marks are set to the temperature differentials. Examples of differentials, and the corresponding relative humidities and dew points, are charted later in this chapter.

The dry bulb thermostat is operated as is; the wet bulb thermostat requires a wick over its bulb. The free end of the wick is suspended in a well of clean water. The entire wick is kept wet by capillary attraction. The water supply to the wet bulb well should be at the conditioned room temperature. Colder or hotter water will alter the reading. Distilled water or cooled condensate from the heating coil is preferred since it is free from foreign matter and mineral salts. However, to cool or temper the condensate to the desired degree, 15 to 25 feet of $^1/_4$-inch O.D. copper tubing is used; the major portion of the tube must be located within the conditioned room, or in the return-air stream. The wick should be changed for each 48 hours of service. A repeatedly washed wick is better than a new wick, since the natural oil in cotton fabric is gradually eliminated by washing. It is difficult to obtain cotton tubing without its natural oil. The slightest oil present repels water.

A stream of air with a velocity of about 600 feet per minute causes the water held by the wick to evaporate to obtain the lowest wet bulb depression, or lowest temperature. This reflects the moisture content of the atmosphere, in degrees, in the most exact manner. The accuracy may be destroyed by haphazard conditions or neglect. An unclean wick, contaminated with silt or mineral deposits, retards evaporation. Low velocity, or even high velocity, of air over the wick will alter its ability to reflect true temperatures. If the wick does not fully cover the mercury bulb, the evaporative rate will be slowed and the temperature reflection lowered. Some authorities have mistakenly stated that 95 per cent relative humidity is correct for pan proofing. Assuming a 110 F. dry bulb temperature at 95 per cent relative humidity, a wet bulb of 108.5 F. would be established. One cubic foot of air at this combination would hold in suspension 25 grains of water. However, the dew point temperature would be 108.2 F. only 1.8 degrees away from "rain." This example emphasizes that too many people are ready to accept figures resulting from poorly conceived methods and premises.

Wet Bulb Air Velocity problems may arise from the manner and circumstances of providing the air and directing its velocity. If the fan blade is mounted on a motor shaft, the air should be sucked over the wick rather than blown onto it. This is to prevent heat, which is radiated from the motor, having an influence on the water evaporation from the wick. The fan blade and the motor should be separated by sufficient insulation to prevent heat transference. The thermostats may be mounted with their bulbs inserted in the return air duct, providing the normal air velocity is close to 600 feet per minute.

Alternate Thermostatic Means.—There are many other control means available, but none of them can equal the accuracy of the mercury bulb thermometer type. Data are obtainable from many sources on the various types of control apparatus. The detail necessary to describe the entire category would occupy more space than justified.

Circuity is of extreme importance in controllability of temperatures and the resultant relative humidity. Let us use a proof box for an example, because it is more difficult to avoid a dew point here than it is in a fermentation room. First, it is of higher temperature and humidity than a fermentation room. Second, more abnormal incidents occur to thwart proof box control. As pointed out previously, a drop from normal steam pressure and volume, or even a fluctuating pressure, is a recurring possibility. Only automatically correcting circuity can accomplish what the thermostat itself cannot do. We have two temperature control methods to begin with, both of which are in current use on manufactured proof boxes. One is the "fixed" dry bulb with the wet bulb differential unchangeable. The other allows the operator to change both dry and wet bulb setting to whatever differential is chosen. The point in question is what happens when either method is not maintained because of the steam crisis.

For instance, a dry bulb thermostat has five fixed settings; the wet bulb has 5 or 10 settings, with a differential of six degrees (and nine degrees optional), plus a "no humidity" setting. These differentials are fixed and cannot be altered. The special feature of this system is that it provides automatic protection against overriding humidification, in the event steam pressure accidentally drops to a low level. If the operator preset the control for 110°F. and then the temperature dropped under 110°F. because of too many open doors, or steam pressure failure, the wet bulb control elements would automatically switch to the next three-degree lower wet bulb setting—namely, 101°F.—corresponding to the 107°F. dry bulb. Thus, the heat and humidity tend to establish the desired six-degree differential in spite of temperature drops. However, on the return rise in heat, the humidity is prevented from coming on until within three degrees of the dry bulb contact or temperature, again preventing over humidification. In the event the heat kept right on lowering past other degree contacts, the wet bulb would automatically, step by step, stay three degrees below the changing dry bulb contact. In brief, the differential between dry bulb and wet bulb is maintained in three-degree steps between 101° to 110°F. dry bulb. The same reaction continues where the top dry bulb temperature is 120°F.

Controlling the temperature in a fermentation room is treated somewhat differently because then we deal with heating, *cooling*, and humidification; requiring sensitive and accurate controls to maintain prefixed wet and dry bulb temperatures in three phases.

TABLE 70

PROOF BOX CONTROLLED TEMPERATURE SYSTEM EXAMPLE

Table of Dry and Wet Bulb Settings and Relative Humidities

Dry bulb setting, °F.	98	101	104	107	110
Wet bulb setting, °F.	92.5	95.5	98	101	104
Relative humidity, per cent	81.3	81.8	80.7	81.8	81.5
Alternate W.B. setting, °F.		92.5	95.5	98	101
Alternate relative humidity, per cent		72.7	73.3	72.5	73.1

Lower relative humidity, as indicated in Table 70 by the alternate wet bulb settings and resultant relative humidities, is available by a three-position toggle switch; on center position all humidity is cut off. The lower humidity is preferred for use with silicone coated pans, or glazed pans, and for other purposes. On the optional lower range, the 98°F. dry bulb setting provides no humidity. This setting is often used for the proofing of raised doughnuts, where a dry atmosphere is preferred to obtain a crusty surface.

A humidity lockout feature prevents the humidity from coming on when a "cold" proof box is started up after a shutdown period. The humidity is "locked out" until the previously selected dry bulb temperature is reached. Thus, an undesirable dew point and the accompanying condensation are automatically avoided. The air heats more quickly than the steel and panels; the thermostat reflects the air temperature only until the steel equals it.

Low heat protection is automatic in this control system. When steam pressure or volume is below recommendation, or when bakery temperature is below 75 F. and dry bulb temperature drops three degrees, the next lower wet bulb contact takes over automatically, reducing relative humidity and preventing condensation or "sweating" on the interior panel surface. When normal steam supply is restored, or when temperature rises, the wet bulb control automatically returns to its original setting.

Automatic Steam Valves are actuated, through a relay, by a thermostat to open when steam is required for heating and humidification and they are usually spring-loaded for closing. Each type of valve has its advantages and disadvantages; the selection must be made in view of the purpose it is to fulfill. The solenoid type has the advantage of being packless, but has the disadvantage of steam overheating its magnetic coil and, also, of leaking into the armature tube, thus shorting the coil. Opening and closing are fast with this type of valve, avoiding underriding and overriding heat or humidity. There is no perfect solenoid type steam valve. Perhaps there is no perfect valve of any type because they all require close attention and maintenance. Motorized valves require several seconds to open and close. They require packing and the usual attention wherever packing glands are found. The motor has a better chance against overheating since it can be ventilated. Modulating valves are workable with steam for heating, but because there is no reliable humidity sensing element that will operate successfully in proof box atmosphere, it is unwise to use them.

THE FERMENTATION ROOM

Room Enclosure

An air-conditioned room must be of such construction that it excludes unwanted temperature influencing media and retains within the room the wanted temperatures. To accomplish this goal a room should be built with steel structural members which support insulated steel-covered panels. This room should be made as airtight as possible to prevent loss of heat from within and to exclude heat gains and infiltration from without. The floor area is of such dimension that it accommodates the number of troughs of a capacity required to satisfy the production rate of the bakery. Heat accumulates from warm floors, walls, equipment, motors, people, troughs, dough, light bulbs, and infiltration. The designer has control over these heat gains only to the extent he can insulate. The total quantity of chilled air to be supplied to the conditioned room is determined solely by its internal sensible heat gains. The entire basis for the design of the air-conditioning system rests on the calculation of these heat gains. The survey of the premises and the calculations must be made

Temperature Pressure Chart
Vacuum--Shaded Figure

Temp. °F	ISO-BU	SO 2	F-12	METHYL	AMMONIA	F-22
-75			23.0	24.9		18.5
-70			21.8	24.3		16.6
-65			20.5	23.5		14.4
-60			19.0	22.2	18.6	11.9
-55			17.3	20.5	16.6	9.1
-50			15.4	19.4	14.3	6.0
-45			13.3	18.2	11.7	2.6
-40		23.5	11.0	15.8	8.7	0.6
-35		22.4	8.4	13.7	5.4	2.7
-30		21.2	5.5	11.4	1.6	5.0
-25		19.6	2.3	9.1	1.3	7.5
-20	14.6	17.9	0.5	6.1	3.6	10.3
-15	13.0	16.1	2.4	3.0	6.2	13.3
-10	11.0	13.9	4.5	0.2	9.0	16.6
- 5	8.8	11.5	6.8	2.0	12.2	20.3
0	6.3	8.9	9.2	3.8	15.7	24.2
5	3.3	5.9	11.9	6.2	19.6	28.4
10	0.2	2.6	14.7	8.7	23.8	32.0
15	1.6	0.5	17.7	11.2	28.4	37.9
20	3.5	2.5	21.1	13.6	33.5	43.3
25	5.5	4.6	24.6	17.2	39.0	49.0
30	7.6	7.0	28.5	20.6	45.0	55.3
35	9.9	9.6	32.6	24.3	51.6	61.7
40	12.2	12.4	37.0	28.1	58.6	69.0
45	14.8	15.5	41.7	32.5	66.3	76.1
50	17.8	18.8	46.7	36.3	74.5	84.7
55	20.8	22.4	52.0	46.3	83.4	92.0
60	24.0	26.2	57.7	48.1	92.9	102.5
65	27.5	30.4	63.7	52.8	103.1	111.3
75	35.0	39.8	76.9	65.2	125.8	131.5
85	43.9	50.6	91.7	79.4	151.7	155.6
86	44.8	51.7	93.2	80.8	154.5	158.0
95	57.7	62.9	108.1	95.4	181.1	185.0
105	64.6	77.2	126.2	110.4	214.2	214.7
115	76.7	93.3	146.5	127.8	251.5	240.6

Fig. 85. Characteristics of Common Refrigerants

with care and accuracy. Tritely stated, undersized air-conditioning systems are never satisfactory; oversized systems are to be avoided.

Location Liabilities

The fermentation room must be located between the mixer and a point where the sponge can get back to the mixer and the dough can get to the dough chute and into the divider. Perhaps only in a newly designed bakery can each piece of equipment be ideally located. In any event, the fermentation room exterior should not be exposed to heat from an oven, to sun heat through a roof, or to a large glass area in a west or north building wall. The western sunload at 4:00 p.m. can be the peak load for the cooling system, necessitating a larger investment. Generally, windows parallel with adjacent fermentation room walls should be bricked in, insulated, and sealed against outside elements. It costs money to heat more than is necessary and, equally, to cool an area from a high temperature down to 80 F. In many existing bakeries there is no choice concerning the most favorable location of the fermentation room, if the building walls must be a part of the fermentation room.

Insulation

A definite key to the required capacity of the conditioning unit lies in the amount of insulation used in the walls, ceiling, and sometimes the floor. The better the insulation used in the room, the less cooling capacity from the cooling coil is required. If more and better insulation is used in the construction of the room itself, less evaporator temperature is required and, therefore, less dehumidification occurs. If we dehumidify less, we also need to humidify less. If we spend more for insulation, we spend less for conditioning equipment and, at one and the same time, improve the controllability of the room.

Height

A prevailing belief among the uninitiated is that the lower the fermentation room ceiling height, the easier the job of maintaining proper temperature and humidification because the volume of the room is less. This might be true generally, but is a fallacy in fermentation room design. High air velocity has a marked drying effect on dough. More height is a distinct advantage because it permits dispersion of the air and permits additional air changes required to obtain the necessary cooling.

Temperatures

A good air-conditioning system should positively circulate air and provide heat, moisture, and refrigeration to the air in sufficient quantities to enable the maintaining of a dry bulb temperature of 80°F., plus or minus one degree and a relative humidity of 75.7 per cent, plus or minus one-half of one per cent, and it should maintain these specified conditions at all seasons of the year.

Humidification

For a fermentation room there should be two separate systems. One system cools or heats the recirculating air to maintain the 80 degree dry bulb temperature. The other provides moisture to maintain the relative humidity at 75.7 per cent. When the wet bulb thermostat causes moisture to be injected, a certain amount of evaporation occurs, dropping the dry bulb temperature of the atmosphere as much as three degrees. Where the thermostatic control is sufficiently sensitive, the momentary cooling effect will cause the heating coil to react to restore the heat, if required. When the water supplied for humidification is the same temperature as the room atmosphere, superior results are obtained.

Dehumidification

It is neither economically, nor atmospherically, desirable to dehumidify the air in a fermentation room. However, the cooling coil condenses moisture out of the air to an extent dependent on the temperature of the coil. The excessive elimination of moisture from the atmosphere, passing through the coil face area, causes the humidifying system to operate more nearly continuously to restore the cyclically eliminated water. A normal fermentation room will have six air changes per hour; therefore, the cubic feet of air in the room will pass through the cooling coil six times an hour. In a room with ceiling height greater than eight feet, the volume increases for the same floor area, and more air changes per hour are permissible. In the event the cooling load is above normal, this condition will prove of advantage since the velocity through the cooling coil may be increased, and so more B.t.u. obtained at a lower discharge temperature, thus decreasing the elimination of water.

Air Distribution

The reconditioned atmosphere should be released to the room and distributed equally to prevent drafts or stratification. The number and nature of air diffusing outlets depends on the height of the room. In no event should an air stream pass over a dough surface, since it would have an evaporating effect and, therefore, would crust the dough. The fewer the air changes, the more beneficial the atmosphere remains. A contradictory situation arises between setting up fewer air changes per hour and, at the same time, obtaining sufficient air velocity over the coil to transfer heat at a rate sufficient to maintain room temperature at 80 F. In comfort conditioning the engineer provides a coil and air velocity to obtain the necessary cooling or heating; letting the number of air changes be what they will. However, the designer for fermentation conditioning requires, also, a knowledge of bakery processing.

Air Washer

It is our belief that the spray air-washer evaporative type of conditioning is detrimental to the fermentive process. So-called "fresh air" is continuously introduced through the washer and into the fermentation room. The expelled air continuously removes carbon dioxide as rapidly as it is released from the dough.

Carbon Dioxide

The influence of carbon dioxide should be discussed in more detail. Since carbon dioxide is one and one-half times heavier than air, a blanket of gas (generated by the yeast) lies over the dough surface until the dough rises to the top of the trough. Then, the gas spills to the floor level or to the previous top level of the gas itself. This gas has a beneficial effect on fermentation. However, if the surrounding atmosphere is permeated with carbon dioxide, breathing becomes difficult for the personnel who must enter the room. This situation is easily remedied by providing an opening, say ten inches in diameter, in the room doors, at a level a little higher than the highest trough. This method permits the gas to flow to the outside at this level and prevents it from rising to the breathing level. Moreover, it eliminates bringing in outside air, which would lower the concentration of the carbon dioxide.

Conditioning Unit

The air-conditioning components may be assembled in a relatively small housing, which should be made of stainless steel in all instances. The radiator and the cooling coil may be located in the same housing, about twelve inches apart, the most preferable distance depending on the relative face area of each. Sometimes a damper is installed to divert the air stream over one or the other of the coils, as either is activated. However, since the radiator face area is smaller than the face area of the cooling coil, and since the room requires considerably less heating than cooling, it would appear that dampers are not worth their cost. The cooled air temperature is so comparatively moderate that coil B.t.u. capacity, whether from chilled water or Freon-12 cooling medium, demands calculated consideration. All the cooling permissible, with as little dehumidification as possible, is the objective. A blower size is determined by calculation to obtain the desired velocity at the static pressure of the system. The blower runs continuously; the heating or cooling functions intermittently, subject to the call of the thermostatic controls.

The ***Psychrometric Chart*** is a fundamental and comprehensive tool for the use of the air-conditioning engineer; and with it he can obtain the complete solution to an air-conditioning problem involving heating, humidifying, cooling and dehumidifying, evaporative cooling, chemical drying, mixing air under different conditions, preheating, reheating, booster heating, or by-passing, or any combination of these. However, the chart cannot solve the technology of fermentation. The engineer needs to know the technical fundamentals of air conditioning, plus equal technical fundamentals of bakery practice—particularly those involved in the fermentive process.

ESTIMATING THE REFRIGERATION HEAT LOAD

The amount of heat that the evaporator or cooling coil must absorb, the refrigerant must carry away, and the condenser must dissipate, is called the "heat load." The heat that is in the fermentation room, and must be removed, constitutes the heat load and comes from several sources:

(A) The heat that leaks through the walls, floor, and ceiling of the room.

(B) The heat from the movable contents of the room; from the doughs and sponges, which rise in temperature as a result of the fermentation process; and from the steel troughs.

(C) The heat given off by electric lights; by the motors and other electrical devices; and by the people, when they are within the room.

(D) The heat entering the room via infiltration, mainly as a result of the opening and closing of doors. (The heat load is increased considerably where the production superintendent insists that the door remain open, or that no door be provided.)

(E) The heat that must be removed from the air to cool it, and moisture from condensation on the evaporator or coil. (Since the room atmosphere relative humidity is held at a high percentage, the evaporator should not be any colder than actually required.)

Heat-leakage-load is dependent on the number of square feet in the room walls, ceiling, floor, and the amount and type of insulation. Various insulating materials do not have the same insulating values. The "K" factor is the conductivity of heat, expressed as a decimal fraction of a B.t.u. that will leak through one square foot of that insulation, if it is of one-inch thickness, and if the temperature difference between the two sides is one degree. Therefore, the total heat leakage will be: Area (in square feet) times "K" factor, times temperature difference, divided by the thickness of the insulation (in inches).

One watt hour of electricity is equal to 3.415 B.t.u. Therefore, a 50-watt bulb burning one hour introduces 170¾ B.t.u. per hour, or 4,100 B.t.u., if allowed to burn 24 hours. Dough has a specific heat of 0.88 B.t.u. per pound, per degree of rise. Normally, this factor is not worth calculating when the designer through experience is able to make a lump allowance. Following the calculation and estimation of losses and other factors, the selection of the evaporator and condensing unit must be made.

The condensing unit should have a "rest" and still maintain the same fermentation room temperature despite variations in "load" through summer or winter. For this reason it is necessary to use a condensing unit somewhat larger in capacity than the expected maximum 24-hour heat-load. The condensing unit should operate only about two-thirds of the time during the fermentation room total operating period. This calls for increasing the condenser unit capacity about 50 per cent. Assuming the heat-load for 24 hours to be 96,000 B.t.u., and the room to be in use for 16 hours per day, the condenser unit must have a capacity of 6,000 B.t.u. per hour.

The capacity of a condensing unit varies with the evaporator temperature and suction pressure (which is governed by the evaporator temperature). Assuming the heat-load calls for 6803 B.t.u., the condensing unit of three-fourths horse power would have a B.t.u. capacity per hour of 5,820, and a one horse power unit would have a B.t.u. capacity of 8,190—somewhat more than required since we need only 6,003. Therefore, we use the one horse power condensing unit and, while it is in operation, it refrigerates at the rate of 8,190 B.t.u. per hour (if the evaporator can absorb heat at that rate) when the evaporator temperature is 25 F. and the suction pressure (Freon 12) is 24.6 pounds per square inch. We must select an evaporator that, at a 15 degree temperature differential, would have a capacity of at least 8,190 B.t.u. per hour. The difference would be that, within a span of 24 hours, the one horse power setup would operate but 13 hours. Briefly, we calculate, select, and design to obtain a neat balance by compromise.

PRINCIPLES OF REFRIGERATION

The subjects "refrigeration" and "air conditioning" are interwoven and, while each in itself has separate applications, no full air-conditioning application can be made without use of refrigeration in some form. There is specific application of both in the baking field. The following discussion of these subjects is presented in the simplest language permissible, so that those with the least knowledge in this specialized field will gain some benefit, and those who know the subject will not be bored or too critical. Some technical language is mandatory, of course.

The modern bakery depends upon refrigeration in practically every phase of its manufacturing process. Separate units are utilized wherever needed. Just as individual machines are powered by individual motors, individual compressors are utilized wherever cooling is required.

While there are several different devices which can be used for the purpose, we will confine our discussion to the mechanical type of compressor and to the use of Freon-12 as a refrigerant. Refrigeration is a process of heat transfer from one space to another space of higher temperature. Our application is, in effect, to pull the temperature down, within an enclosed space. The heat pump development, the reverse operation for heating an enclosed space, is a phase which is not pertinent here. However, it is a part of the refrigeration picture which later may be adaptable to bakery uses.

The process of mechanical refrigeration can best be explained by comparing it with a steam heating system. The principles are similar but the flow of heat is reversed. Heat is supplied to the boiler by some type of burner. The heat is used to evaporate the water to steam. The steam is then piped to a radiator in which the steam condenses, giving up its heat content to the surrounding media of the radiator. The condensate or water is then returned to the boiler, by the way of a water pump, to repeat its cycle of operations.

The refrigeration system is the reverse of the boiler system. The "boiler" in a refrigeration system is known as an evaporator, or more often, as the cooling coil. The evaporator absorbs heat from the air or surrounding media, causing the liquid refrigerant to evaporate at a low temperature and maintain a pressure on the evaporator.

The boiler "feed" water pump is comparable to a compressor. The compressor pumps the gas out of the evaporator and raises it to a high pressure. As the pressure is raised, the temperature of the gas is increased. This high temperature gas is pumped by the compressor to the condenser, which corresponds to a radiator in a heating system, where it is cooled by the surrounding media (air or water). Upon cooling, the gas again becomes a liquid. The liquid refrigerant is then admitted back to the evaporator by use of an expansion or regulating valve. The boiler and the evaporator are also similar in another respect too. Other things being equal, the capacity of a boiler or an evaporator is proportional to its surface area. The more boiler area, the more steam; the more evaporator area, the more cooling capacity.

With the above simplification as background the function of the compressor, condenser, evaporator, expansion valve, and the maintenanc phase can be gone into further. First, the fundamentals on which all refrigeration and air-conditioning is based will be presented.

The Refrigerating Cycle

Fig. 86 schematically illustrates an idealized refrigeration cycle. At the left is a closed vessel or evaporator of Freon-12 in a box that is to be cooled. The walls of the box are filled with cork, rock wool or other insulating material in order to retard the flow of heat into the box or "refrigerator." If the pipe from the evaporator leads out to the open air at sea-level pressure (zero gauge) the Freon-12 will boil at about −22° F.

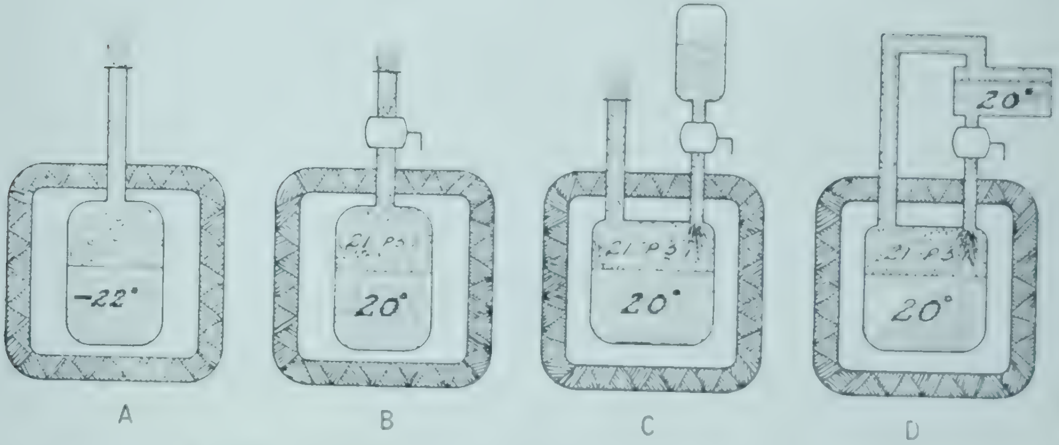

Fig. 86. Development of the Refrigeration Cycle

If we now put a valve in the outlet pipe in order to partly retard the escape of Freon-12, the pressure will rise to, e.g. 21 p.s.i.g. This situation is illustrated in part B of Fig. 86. At 21 p.s.i.g. the Freon-12 will boil at 20° F. instead of −22° F. By increasing the pressure in the evaporator from 0 to 21 p.s.i.g., we have brought the evaporator temperature up from −22° to 20° F.

If, instead of restricting the escape of Freon-12 vapor, we restrict the flow of liquid into the evaporator to keep a constant pressure of 21 p.s.i.g., we produce the same effect. That is, the boiling takes place at 20° F. because the pressure is at 21 p.s.i.g. Part C of Fig. 86 illustrates this arrangement. However, we are still losing Freon-12 vapor into the air. If, as in part D, we lead this vapor to another closed vessel that is kept at 20° F., the vapor will condense there and become a liquid again, so that it can be fed back to the evaporator, and the cycle repeated continuously.

From these examples it will be seen that the heat in the refrigerator goes into the evaporator and the vapor formed there carries the heat out to the condenser where it is cooled. As its temperature is reduced, the vapor condenses to its liquid form. Thus we have moved the heat from inside the refrigerator to the outside, employing the refrigerant as the carrying agent. Obviously, we will not have in any normal situation a means for cooling the condenser to 20°F. We need to be able to take the heat out of the vapor at a higher temperature, say 70°F., and cause it to condense to a liquid.

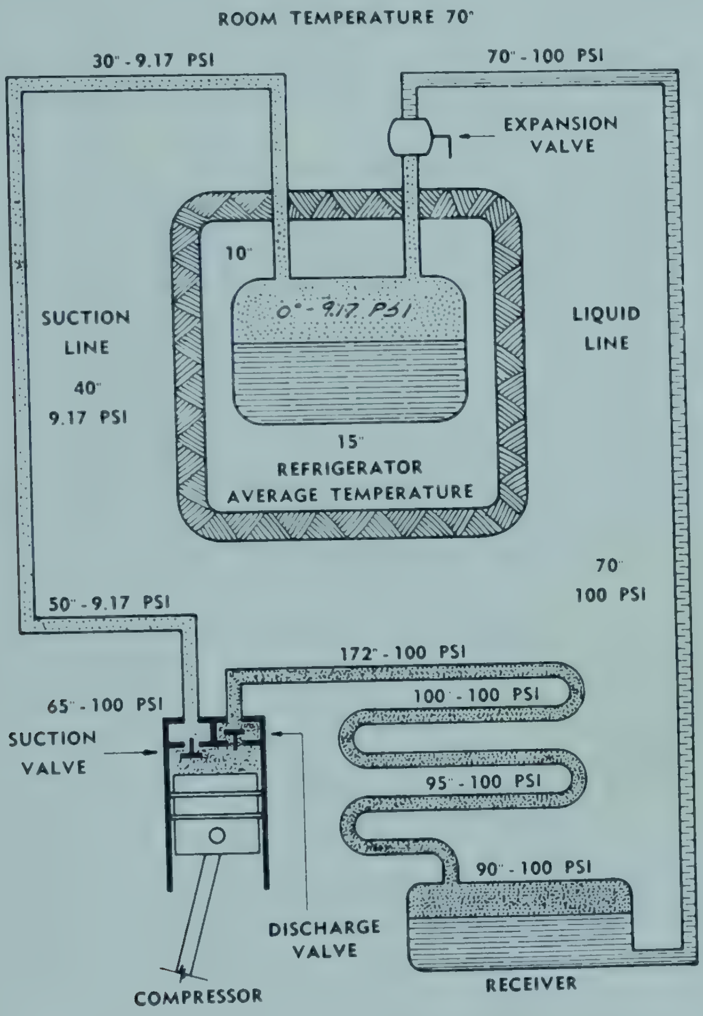
ROOM TEMPERATURE 70°
30° - 9.17 PSI
70° - 100 PSI
EXPANSION VALVE
10°
0° - 9.17 PSI
SUCTION LINE
40°
9.17 PSI
LIQUID LINE
15°
REFRIGERATOR
AVERAGE TEMPERATURE
70°
100 PSI
50° - 9.17 PSI
172° - 100 PSI
100° - 100 PSI
65° - 100 PSI
SUCTION VALVE
95° - 100 PSI
90° - 100 PSI
DISCHARGE VALVE
COMPRESSOR
RECEIVER

Fig. 87. Refrigeration Cycle

The condensing pressure and temperature of a refrigerant is the same as its evaporating pressure and temperature. If it is in liquid form and heat is added, it boils and turns into vapor at a certain pressure and temperature. If the same amount of heat is removed from the vapor, it turns back into a liquid. Moreover, the heat does not have to be removed at the same temperature and pressure at which it was added. It can be removed at much higher temperatures, provided that the pressure is also higher. The relationship between temperature and pressure of liquefaction for several common refrigerants is illustrated in Fig. 85. Therefore, if we can raise the pressure of the escaping refrigerant in the previous example to 100 p.s.i.g. from 0 p.s.i.g., the vapor can be cooled and condensed to a liquid at 70°F.

To raise the pressure from 0 to 100 p.s.i.g., the vapor is compressed by a special type of pump called a compressor. The higher pressure corresponds to 90° F. so that the compressed vapor would be cooled by 70° F. air.

The condenser usually takes the form of a series of tubes with fins to make it easier for the heat to be absorbed by the air. To make the transfer of heat from the condenser to the air still easier and more rapid, a fan is often used to blow or draw air over the condenser tubes and fins.

The compressor shown in Fig. 87 is the piston or reciprocating type, but it could be the rotary or any other suitable type, so long as it compresses the low pressure vapor from the evaporator to an extent sufficient to allow it to be condensed at higher temperatures.

The low pressure, heat-laden vapor comes from the evaporator at 9.17 p.s.i.g. and 10° F., but by the time it gets to the compressor it has picked up some heat and has been warmed or superheated to 65° F. It is still at 9.17 p.s.i.g.

In the compressor, the pressure is raised so that the vapor goes into the condenser at 100 p.s.i.g. In compressing the vapor, work was done on it and this work energy was transformed into heat that raised the temperature of the vapor to 172° F. We are assuming that the room temperature is 70° F., but the condensing temperature must be higher so that heat will flow from the condenser to the room air. For our example, let us use a 20° F. temperature differential which will give us a condensing temperature of 90° F. before it will start to condense; that is, sensible heat (superheat) must be removed before we can start taking out the latent heat. The superheat is much less than the latent heat, usually about one-fourth of the latent.

After the vapor has lost its super-heat and latent heat and has been reduced to a liquid, still at 90° F. it passes into the "receiver," which is merely a storage tank for holding the surplus liquid until we are ready to use it.

The 100 lbs. pressure forces the liquid out of the receiver and through the liquid line and the evaporator as fast as it is used (boiled) in the evaporator. By the time the liquid gets to the evaporator it cools down still more and eventually may get down to near the 70° F. temperature of the room air. This is known as "sub-cooling" the liquid. The heat lost to the room air is sensible heat only and the pressure remains at 100 p.s.i.g.

The pressure in the evaporator must be kept at 9.17 p.s.i.g. if we expect the liquid to boil at 10°F. Since the liquid is actually at 100 p.s.i.g., a restrictive device of some sort must be used to reduce the liquid down to the appropriate pressure. This may be accomplished by a kind of hand valve, called a hand expansion valve, or it may be an automatically operated valve.

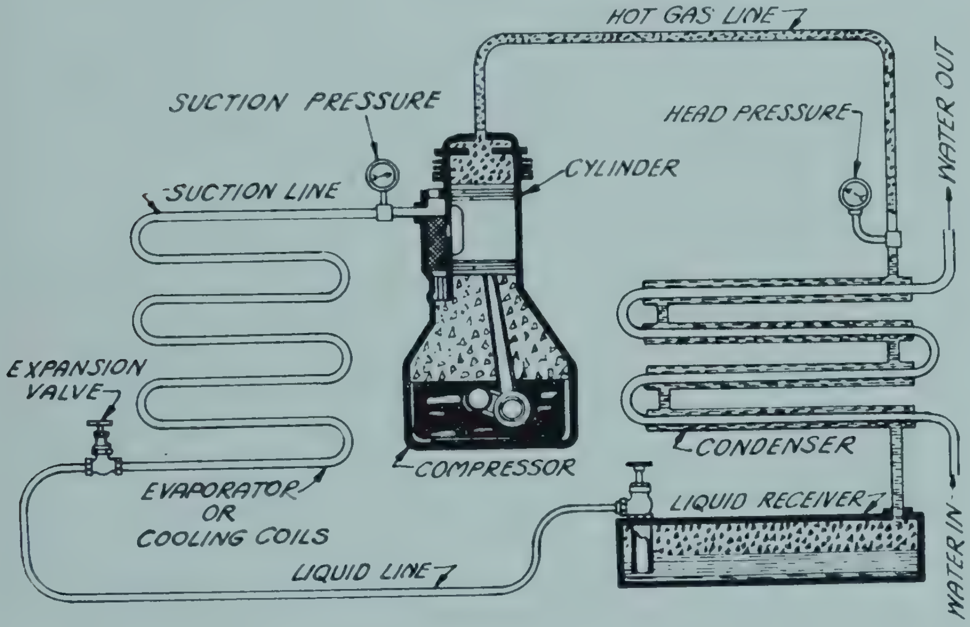
HOT GAS LINE
SUCTION PRESSURE
HEAD PRESSURE
WATER OUT
CYLINDER
SUCTION LINE
EXPANSION VALVE
COMPRESSOR
CONDENSER
EVAPORATOR OR COOLING COILS
LIQUID RECEIVER
LIQUID LINE
WATER IN

FIG. 88. HOW REFRIGERATION PRINCIPLES ARE APPLIED IN PRACTICE

To summarize the preceding discussion, the refrigerant (Freon-12 in this discussion) is first vaporized in the evaporator where it takes up heat and carries it away. Thus it cools or refrigerates the cabinet. The vapor is then compressed in the compressor and goes into the condenser where it gets rid of the heat it picked up in the evaporator. In so doing, it turns into a liquid that is capable of absorbing more heat during evaporation. These steps provide a continuous cycle, permitting the refrigerant to be used over and over again. The refrigerant is merely the agent for moving the heat, and the compressor and condenser (comprising, with a motor, receiver, etc., the condensing unit) are simply the components of a salvaging machine that recovers the vapor and puts it back into liquid form so that it can be used again. Fig. 88 illustrates a complete system of this type.

Maintenance and Operation

A great many of the problems of operation and maintenance can be traced back to the original installation, being the result of improper sizing of lines, inadequate securing of lines against vibration, and the omitting of auxiliary equipment such as sight glass gauges, oil traps, etc.

Heat exchangers are frequently installed between the liquid and suction lines to cool the liquid refrigerant flowing to the expansion valve and to warm the cold suction gas. Cooling the liquid properly will prevent the formation of flash gas in the liquid line and will insure maximum expansion valve capacity. This is particularly important when the expansion valve must be located any appreciable distance above the compressor. Increasing the heat of the suction gas is advantageous in that it tends to evaporate any liquid passing into the suction line, thus affording some protection against "flooding back."

Water vapor or moisture will cause trouble in any refrigeration system. At low temperatures, the moisture may freeze in the expansion valve orifice or plug the fine screen in the strainer. It may also induce serious corrosion or create sludge in the compressor crankcase. In spite of every effort that is made to keep moisture out of the system, some will usually find its way in. To remove this moisture, various forms of driers or dehydrators are used. Driers are packed with a desiccant, usually silica gel, which is retained in the body of the drier by means of a fine screen. These driers will, therefore, act as both strainers and dehydrators. Since driers of this type add a certain amount of resistance to the liquid line, some installers make a practice of using the drier only temporarily. The drier is placed in the line, the system is operated for a week or so, and the drier is then removed. A better practice is to install a drier with a three-valve by-pass which permits operation either with or without the drier.

Strainers or filters are intended to remove particles of foreign matter from the liquid or gaseous refrigerant before they can obstruct valves or damage the compressor. The strainer, or liquid-line filter, should always be installed ahead of any expansion valve or magnetic stop valve. When the solenoid or magnetic stop valve and the expansion valve are installed close together, a single strainer ahead of the magnetic stop valve may be used. Similarly, a suction strainer should always be installed immediately ahead of any evaporator pressure regulator or back pressure valve. If the compressor does not have a built-in suction screen, a suction strainer should always be installed ahead of the compressor shut-off valve.

When compressors or condensing units are mounted on resilient bases, the use of flexible connectors in the refrigerant line is imperative. The flexible connectors commonly used to take the form of metallic bellows protected by woven wire sheaths.

Sight glasses or liquid indicators should be installed in the liquid line of every system. They are usually placed near the liquid shut-off valve on the receiver or condenser, and are used to tell whether or not the system is fully charged. If the liquid level in the receiver or condenser is too low, some gas will escape into the liquid tube and will appear at the sight glass in the form of bubbles. Sight glasses are available with one or two lenses. The double lens form is recommended since otherwise it is often difficult to observe the condition of the liquid when the equipment is located in a dark place.

Gauges are relatively inexpensive and should be used freely. During testing, gauges must be connected to both the suction and the discharge side of the compressor. If an evaporator pressure regulator or back pressure valve is used, a third gauge must be installed on the upstream side of the regulator in order to determine the evaporator pressure. While it is not difficult to attach service gauges to the compressor by means of the back seat tapping of the suction and discharge valves, a gauge cannot be attached to the back pressure valve unless the system is pumped down. It is always good practice to install gauges permanently. When so installed, the gauges should be protected by throttling valves.

Because the compressor must be lubricated, the refrigerant gas comes into intimate contact with the lubricating oil on the cylinder walls of the machine. Some of this oil is carried into the discharge line by the refrigerant and on to the condenser and receiver. To insure that the compressor does not run short of oil, the system must be designed to carry this oil, with the refrigerant, on through the evaporator and back to the compressor, or oil traps may be installed with an oil return to the compressor. Location of the compressor should be below the location of the cooling coil, where possible, to prevent oil from being carried to the coil.

Preventative Maintenance Schedule

Weekly.—(1) Check the oil level in the compressor. If the oil level appears to be low, the systems should be allowed to operate continuously for 3 or 4 hours during which time the oil level should be checked every 30 minutes. If the level continues low, add oil.

(2) If the compressor has force feed lubrication, the oil pressure should be checked. The oil pressure gauge should read about 25 lbs. higher than the suction pressure.

(3) The compressor should be stopped and the seal checked for evi-

dence of excessive oil leakage. If excessive leakage is found, the seal should be tested with a halide torch for refrigerant leakage.

(4) The entire system should be checked for any unusual conditions.

Monthly.—(1) All motors and fan shafts should be checked for adequate lubrication. Oil lubricated sleeve bearings may require the addition of a small amount of oil. Over lubrication should be avoided. Grease-lubricated ball bearings should be lubricated about once every three months.

(2) All belts should be checked for proper tension and alignment. If each belt can be depressed about one-half inch with normal pressure from the thumb, the tension is about right.

(3) Pulleys and sheaves should be checked for tightness on shafts. If found to be loose, they should not be tightened unless alignment has been checked and corrected.

(4) If the system is equipped with gauges, and it should be, the head pressure should be observed. If the head pressure is higher than normal, the cause should be determined and corrected. Purging air or other non-condensible gases from the system may be necessary.

(5) If an evaporative condenser or cooling tower is used, the conditions of the sprays and suction screen should be checked. If algae or scaling are evident, water treatment is necessary. The spray pump should be checked for defects.

Yearly.—1. Water should be drained from all parts of the condensing system and a complete and careful inspection should be made. Fouled condenser tubes should be cleaned. Scale should be removed.

2. If an evaporative condenser or cooling tower is used, the pumps and tanks should be thoroughly flushed, and any rust or corrosion scraped away prior to painting. All surfaces should be painted.

3. All motor and fan shaft bearings should be checked for evidences of wear. Shafts should be checked for proper "end play adjustment."

4. All strainers in the water piping should be cleaned.

5. Frayed or worn belts should be replaced.

6. The condition of the drains should be checked. They should be free and should carry away all waste water without danger of stoppage and flooding.

7. The condition of the contacts in all starters and controls should be checked.

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CHAPTER 16

Samuel A. Matz

Make-up Equipment

INTRODUCTION

After the dough leaves the fermentation room, it is processed by a series of devices which are rather loosely classified as make-up equipment. In manufacturing of pan bread, this category is comprised of the divider, the rounder, the intermediate proofer, and the moulder. Except for the intermediate proofer, these devices have the common function of changing the shape of the dough piece. These pieces of machinery form an integrated group and they must be discussed together for maximum clarity. Problems encountered in operating and maintaining the various machines are similar, and they must operate in unison and at the same rate for maximum efficiency. Furthermore, the dough is at approximately the same state of chemical and physical development throughout its processing in the make-up equipment.

Although the intermediate proofer is discussed in this chapter, it certainly is not "make-up equipment" in the usual sense, because it does not change the shape of the dough piece. It is included here because it is a necessary connecting link between the other parts of the complex, and consideration of the other members of the chain, i.e. the divider, rounder, and moulder, would be made more difficult and less understandable if a description of the intermediate proofer were not included.

The subject of forming equipment is so complex and diverse that it was mandatory to adopt some plan for limiting the contents of this chapter. The largest amount of space has been devoted to bread-making equipment. Special forming machinery for other bakery products will also be discussed, but not in the same amount of detail used for bread make-up machines. It is felt that this limitation is justified not only by considerations of available space, but also by the relative importance of bread-making devices and by the applicability of their principles of operation to other less common types of forming machines.

A commercially available example of each major type of device considered will be illustrated and described. These discussions will be limited to equipment suitable for wholesale or large retail bakeries. There are several good books on small retail shop practices and procedures already available to readers who are interested in this aspect of the bakery arts, and there would be little justification for duplicating such coverage in this volume. On the other hand, the lack of organized discussions of mass production equipment dictates the fullest possible use of the presently available space for consideration of this type of machinery.

It has been assumed that the reader has a least a fair grounding in the basic sciences. Some acquaintance with bakery technology is also desirable, even though the first two sections of the book include a review of many aspects of the technology. The principal value of the present chapter will be to the present or potential engineer or scientist who plans to specialize in bakery technology. The level of difficulty is intended to be such as to make the contents readily understandable to a college graduate.

Current procedures and machinery are emphasized but some historical material is included when it is considered necessary for a better understanding of the present state of the art. Trends and the reasons for trends are discussed in relation to the past.

Examples are chiefly confined to United States practices. It is recognized that these are not the most advanced in every case, but they are likely to be the most important to the reader. Where important and valuable deviations from United States practices are thought to be readily applicable to situations existing in this country, they are discussed briefly.

DIVIDERS

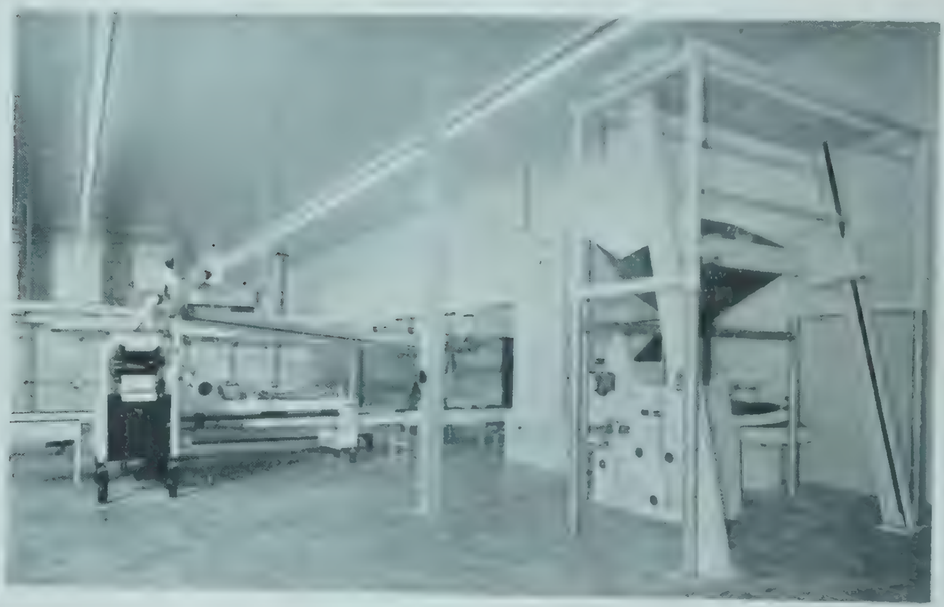
Transporting the Dough to the Divider

After the dough has completed its fermentation in bulk, the filled trough is transported, usually by man-power, to the divider area or to the floor above the divider. Transfer of the trough contents is effected by gravity to the divider hopper or to a chute leading to the hopper. The trough contents may be transferred to the raised hopper of the divider either as one mass or as chunks, depending upon the capacity of the hopper and the available equipment for handling the trough. Usually, the trough is elevated and then tipped so that the dough falls into the divider chute. Fig. 89 illustrates a typical arrangement of the trough elevator and the divider. The trough, which is on casters, is rolled along the floor and into the brackets of the elevator (in the illustration the empty brackets are in a raised position), the elevator motor is started, first raising the trough above the divider and then turning it through a 90 degree angle to dump the dough into the divider hopper.

Function of the Divider

In brief, the function of the divider is to cut the dough into loaf-sized pieces. The important factor to the baker is the loaf weight, but it has proved to be difficult to design an apparatus which will subdivide dough on a weight basis. Consequently, all dividers presently used operate on a volumetric basis. The dough is forced into spaces having a known volume, the pocket contents are cut off from the main dough mass, and the pieces of constant volume are ejected onto a conveyor leading to the rounder. As long as the dough density is kept constant, the weight as well as the volume of the pieces will be the same.

Fig. 90 is a schematic diagram of the most common type of divider. The dough flows from the hopper into the underlying compression chamber. At the start of the cycle, a knife moves horizontally to cut off the piece of dough near the hopper bottom. Next, the ram or piston moves forward pressing the severed dough piece into a chamber contained in a rotatable cylinder. At the end of the ram stroke, the cylinder turns, cutting off the excess dough, and, finally, the discharge lever ejects the measured dough piece.



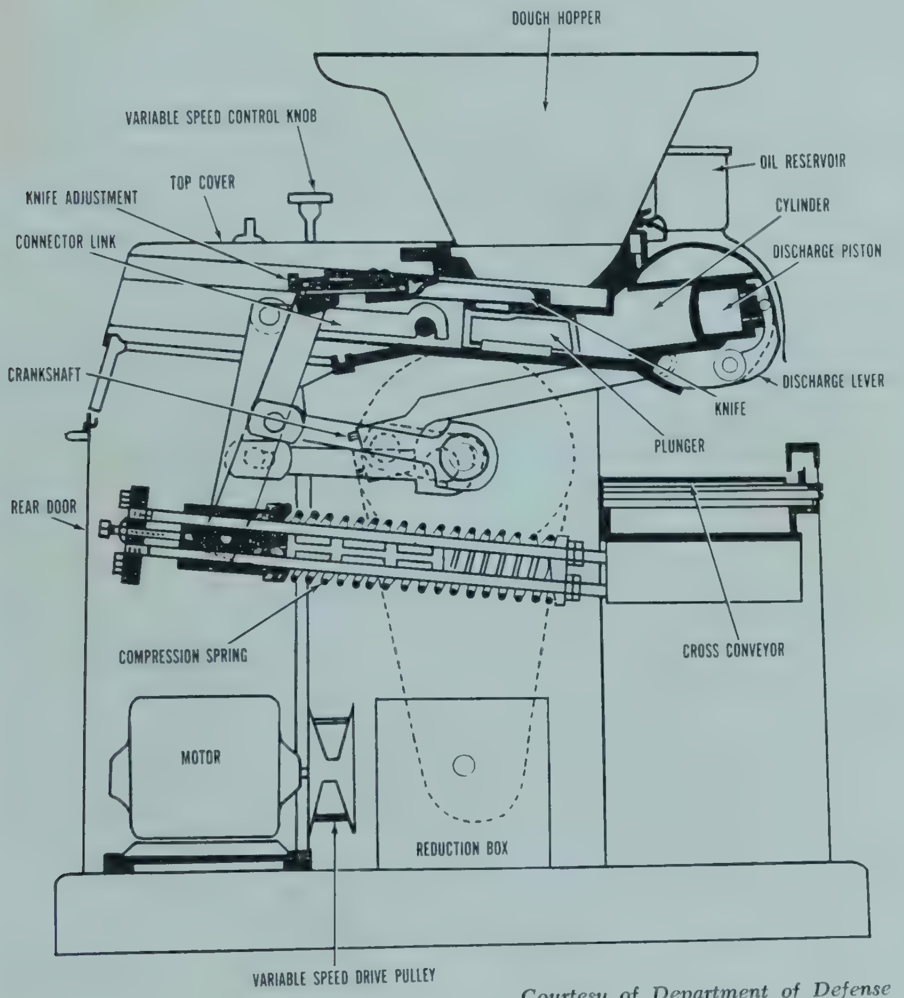
Courtesy of Baker Perkins, Inc.

FIG. 89. DOUGH TROUGH ELEVATOR ARRANGED TO FEED A 6-POCKET DIVIDER, A ROUNDER, AND A 6-POCKET PROOFER

In the return cycle, the emptied cylinder is turned back so that the cavities face the compression chamber, and the knife and compression piston withdraw, allowing more dough to be drawn into the chamber by gravity and suction.

Commercial models are available which have from 2 to 8 pockets in the cylinder and operate at speeds up to 25 strokes per minute. Scaling range is from 6 to 36 ounces, and motors up to 7½ horsepower are used.

An eight-pocket divider is shown in Fig. 91. This machine will scale dough pieces at a speed of 2400 to 9600 loaves per hour. It is 5 ft. $3^1/_2$ in. high, 5 ft. $6^1/_2$ in. long, and 3 ft. 5 in. wide. A special feature of this model is the variable speed drive on the discharge conveyor.


DOUGH HOPPER
VARIABLE SPEED CONTROL KNOB
OIL RESERVOIR
TOP COVER
KNIFE ADJUSTMENT
CYLINDER
CONNECTOR LINK
DISCHARGE PISTON
CRANKSHAFT
DISCHARGE LEVER
KNIFE
PLUNGER
REAR DOOR
COMPRESSION SPRING
CROSS CONVEYOR
MOTOR
REDUCTION BOX
VARIABLE SPEED DRIVE PULLEY

Courtesy of Department of Defense

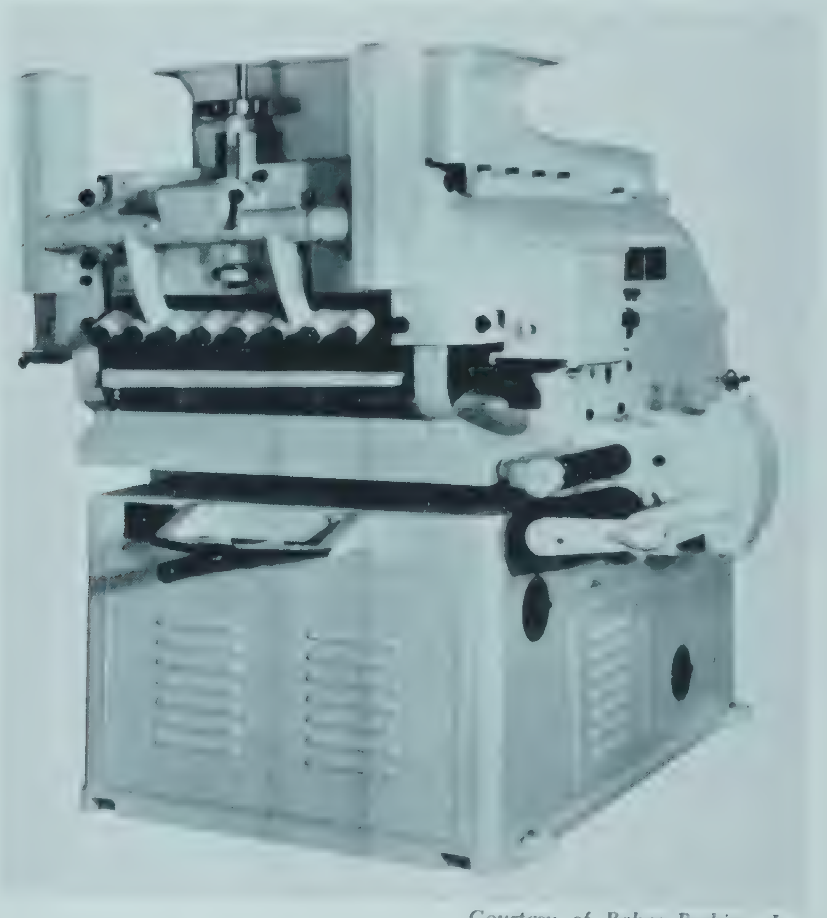
FIG. 90. SCHEMATIC DIAGRAM OF A COMMON TYPE OF DIVIDER

Some dividers use a reciprocating division box instead of the rotating cylinder to measure and cut off the dough pieces. In these machines, the box containing the pockets is forced downward after they are filled, shearing off the excess dough as a result of the movement of the pockets past the chamber edge.

A warm air current is sometimes provided on the conveyor leading from the divider to the rounder in order to partially dry the cut surfaces.

Controlling and Adjusting the Divider

The volume of the pockets which scale the dough piece is adjustable to allow variation in the weight of the finished loaf and to permit compensation for changes in dough density. Volume adjustment is made by trial and error changes of the piston depth in each individual pocket. The pistons are adjusted by different mechanisms in different models. Lock nuts or shims are the usual means. Any change in the density of the dough will be reflected in an alteration of the piece weight measured at any piston setting. Therefore it is essential to set the machine using a representative sample of dough. Allowing the dough to stand around for a considerable period while making adjustments is a sure way to create troublesome conditions later on.



Courtesy of Baker Perkins, Inc.

Fig. 91. An Eight-Pocket Dough Divider

The speed of the apparatus must be coordinated with the speed of other elements in the forming machine complexus. However, top speed of the divider is established as frequently by dough characteristics as by machine limitations. A variable speed drive is provided on all dividers for the adjustment of scaling rate. Changing the speed is simply a matter of adjusting the wheel or lever controlling the variable speed drive.

Dough dividers have a special lubrication system which provides an important variable in machine adjustment. Oil used in this system has two functions: it lubricates the mechanical parts of the divider which come in contact with the dough, and it forms a seal between the dough box and the divider head. It is usually a special grade of mineral oil since it has been found that vegetable oils leave a gummy film which may cause excessive friction or even bind the close tolerance moving parts of the machine. Divider oil should be a colorless, odorless, and tasteless as possible. Specifications commonly call for a technical white grade mineral oil with a viscosity of 85 to 120 at 212°F. and a flash point of 662°F. Lubrication systems are either pressure-fed or gravity types. Adjustment of either is simple. The correct setting is that which uses the least amount of oil to secure proper functioning of the divider. Machine bearings and other moving parts which do not contact the dough are lubricated by the usual petroleum oils and greases.

Since divider oil, which is non-nutritive, is taken up by the dough and appears in small quantities in the finished loaves, it falls under certain provisions of the new Federal legislation regarding food additives. In effect, the current legislation requires prior approval by the Food and Drug Administration for use of food additives of this nature, but allows a moratorium on enforcement until March 5, 1960 for additives which were in use prior to January 1, 1958. Since divider oil has been used for many years, manufacturers and users of the product had until March 5, 1960 to secure approval of the use of the oil in bread. The Federal Register of March 17, 1960 indicated that manufacturers of mineral oil had been given a one-year extension from March 6, 1960, in which to meet the requirements of the Food Additives Amendment with respect to the use of mineral oil as an indirect additive in the processing of bakery products in amounts up to 1500 parts per million when used as divider oil, pan oil, or trough grease.

Maintaining the proper clearances between the knife and the ram and between the dough box and the divider head is very important in assuring proper operation of the machine. Excessive clearance will cause dough leakage, and insufficient clearance will cause the machine to overheat with consequent bad effects on the dough and extra demands on the motor. Consult the manufacturer's recommendations for maintaining the proper clearance between these parts.

The ram and the knife control the amount of dough that enters the dough box, and they are adjustable. If an insufficient amount of dough is taken in, the weights of the pieces will usually be erratic, while an excessive amount of dough will receive unnecessary punishment which may cause poor performance of the dough in the later stages of processing. The former condition is frequently accompanied by a knocking sound in the divider as the partially empty pockets allow gas to be compressed in them. An up and down movement of the dough in the hopper is considered a symptom of poor adjustment, or of dough which is not pliable enough. The adjustments which will produce the best results for any particular dough must be determined empirically.

According to Trautman (1951), breaking of the dough between the divider chamber and the dough hopper is a certain indication of improperly conditioned dough. He also states that it is important for the chute to have the proper pitch so the dough will be given an even pressure at the chamber at all times. Other authorities indicate the chute should have an angle of at least 45° if possible, and under no circumstances should the angle be less than 30°. The surface finish on the dough chute and divider dough hopper is quite important and should be in the neighborhood of 125 disc grind finish. It is sometimes possible to solve problems of proper dough feed to the compression chamber by applying a Teflon coating to the high friction surface.

The amount of flour dusted on to the conveyor belt can be controlled, and should, of course, be kept to the minimum capable of promoting adequate performance of the divider.

Maintenance

Cleaning the divider is a rather difficult job which must be performed whenever the machine is shut down for more than an hour in order to prevent caking of the retained dough. Proper cleaning requires removal of the ram, knife, dough hopper, and pistons.

Following is a recommended sequence for cleaning:

(1) Stop the divider with the knife and the ram all the way back.

(2) Remove the housing covering the knife connecting links and release the knife. Draw the knife out of its guide slots and, if possible, remove it from the machine.

(3) Disengage the ram from its connecting shaft, and draw it out of the dough chamber.

(4) Remove nut holding plunger in cylinder and remove the plunger. Since the pistons are usually not interchangeable, they should be plainly marked if the manufacturer has not provided an identification symbol.

(5) Remove the excess dough from the parts with a hardwood or plastic scraper and finish cleaning with water and soda or detergent. After rinsing and drying, cover the parts with a thin film of divider oil.

(6) Place the oil catch pan under the divider head to protect the conveyor belt and vacuum or blow out all flour from the divider proper, the conveyor belts, motor, drives, and switch boxes.

(7) Clean the inside and the outside of the divider housing.

(8) Replace the plungers, ram, and knife.

So far as sanitary problems are concerned, divider oil will not support insect, rodent, or microbial life. Dusting flour is subject to the usual infestation problems if not carefully watched. Dirty or hardened dough pieces, if allowed to accumulate, can end up in the finished loaves as readily detectable contaminants.

Serious accidents can be caused if the hazardous nature of the divider is not fully recognized. The American Standard Safety Code for Bakery Equipment[1] (Anon. 1947) lists the following desirable safety features for bakery equipment:

"**Pinch and Shear Points.**—All pinch points and shear points from rotating or reciprocating parts of the divider shall be enclosed or guarded, to protect the operator's hands and fingers from these hazards.

"**Front Guards.**—Guards at the front of a divider shall be so arranged that the weight of dough can be adjusted without removing the guard.

"**Rear of Divider.**—The back of the divider shall have a complete cover to enclose all of the moving parts, or each individual part shall be enclosed or guarded to remove the separate hazards. The rear cover shall be provided with a limit switch in order that the machine cannot operate when this cover is open. The guard on the back shall be hinged so that it cannot be completely removed and if a catch or brace is provided for holding the cover open, it shall be designed so that it will not release due to vibrations or minor bumping whereby the cover may drop on an employee.

"**Oil Holes in Knife.**—The oil holes in the knife at the back of the divider shall be of such size that an employee's finger cannot go through the hole.

"**Knife Actuating Arm.**—There shall be a saddle guard or other protective device on any elongate hole in the knife actuating arm at the back of the divider.

"**Shear Pin.**—Dividers shall be equipped with mechanical overload release devices such as shear pins."

In addition to the above, the Code has a general discussion concerning the hazards of dividers which brings out the following points:

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[1] This material is reproduced from the American Standard Safety Code for Bakery Equipment, Z50.1–1947, copyrighted by ASA, copies of which may be purchased from the American Standards Association at 70 East 45th street, New York 17, New York.

"(a) In some dividers the division box goes up and down, causing pinch points.

(b) On another type of divider the cylinder division box revolves and if a man reaches in to grab a "double" he is subject to a shear hazard. A transparent shield is suggested across the front.

(c) At the start of a run the operator grabs the first piece of dough to weigh it. On some machines there is not sufficient clearance between the bottom of the divider and the primary conveyor belt.

(d) Rotating division boxes on some dividers are cylindrical, but with a segment cut off from one side. There is a shear point under the divider drum where this flat side rotates past the edge of the machine.

(e) The pocket adjustment on some dividers is a knurled round knob on the end of a reciprocating bar. There is a pinching hazard between the side of this knob and the side of the box.

(f) There is a shear hazard on some machines where the division box connecting rod end passes the side of the machine.

(g) There is a pinch point on some machines where the top of the division box passes the edge of the hopper.

(h) There is a hazard on some machines where the division box lever is pulled up past the bottom of the division box by the division box connecting rod.

(i) On the primary conveyor of some dividers where the conveyor belt goes over the pulley, there is an exposed pinch point where the belt makes contact with the pulley because the end of the pulley is exposed.

(j) Conveyor-belt connections should be checked for pinch points.

(k) At present certain dividers have relatively large oil holes which sometimes fill with dough and when the employee tries to push out the dough with his fingers there is a shear hazard with the frame below."

Interaction of Doughs and Divider

Anything which affects the dough density will change the weight of the scaled pieces. Since the dough continues to ferment in the hopper, with the gas production contributing to a lower density, a slight decrease in scale weight can be expected as each batch of dough is processed, with a rise as a new batch starts to flow into the compression chamber. If the batches are small enough and divider operation is rapid enough, the changes in piece weight will probably be within limits that can be tolerated. If the divider must be shut down for even a few minutes with dough in the hopper, a considerable error in weight must be expected. Frequent tests of the weight of dough pieces from each pocket should be made by the operator with the aid of an "over-and-under" scale placed adjacent to the conveyor.

Excessively bucky doughs may not fill the divider pockets completely, with resultant erratic scaling. Wide variations in piece weights may also be observed if the dough is full of large gas pockets. Some dividers have been equiped with compression pistons which have rods projecting from their faces so that large gas pockets in the dough will be punctured.

The divider has a pronounced effect on dough properties. The compression and cutting result in a considerable loss of gas, not only initially, but continuing through the cut and torn surfaces of the dough piece as it is transported to the rounder. Furthermore, the compression and cutting actions disorient the gluten fibrils, changing the dough qualities. A temperature increase is observed as the dough passes through the divider, and this affects the fermentation speed, among other things. The temperature change is due to contact with hot divider surfaces and to the mechanical work performed on the dough. The dough also picks up divider oil and flour during its passage through the machine, although, if adjustments are properly made, the amounts should not be great enough to cause a significant change in the dough properties.

ROUNDERS

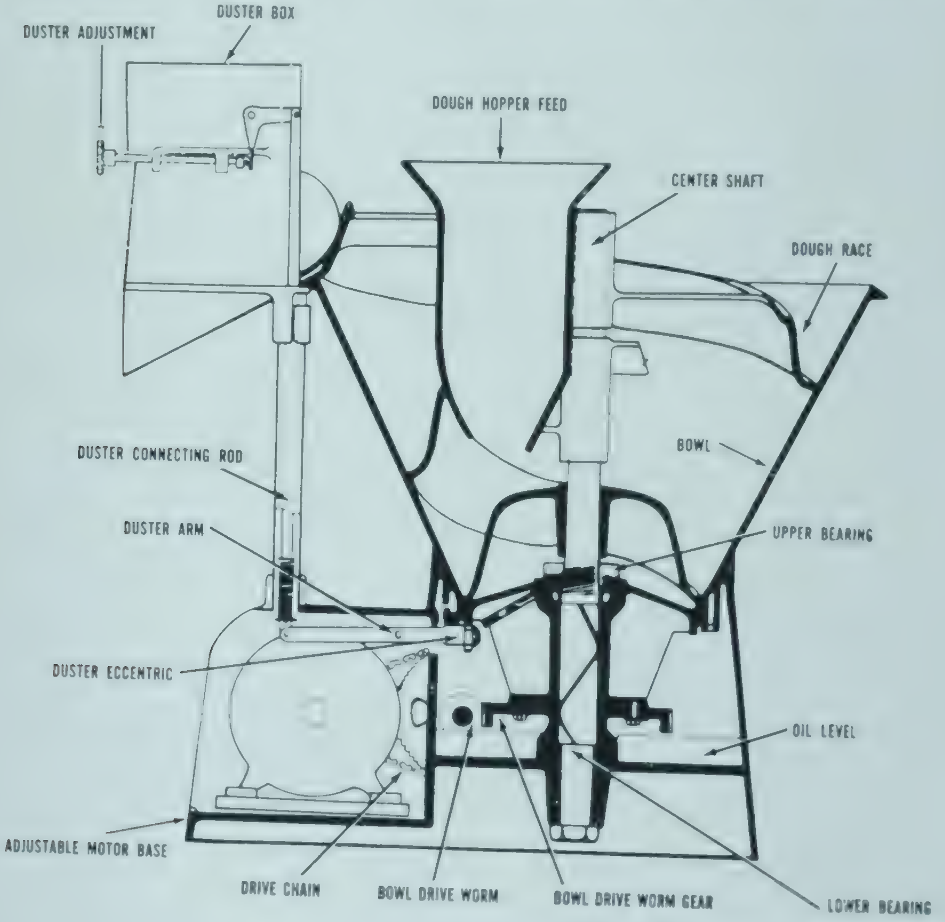
The Function of the Rounder

When the dough piece leaves the divider, it is irregular in shape with sticky cut surfaces from which the gas can readily diffuse. The gluten structure is disoriented and so not in suitable condition for moulding. It is the function of the rounder to close these cut surfaces, giving the dough piece a smooth and dry exterior, to make a relatively thick and continuous skin around the dough piece, to re-orient the gluten structure, and to form the dough into a ball for easier handling in the subsequent steps. It performs these functions by rolling the well-floured dough piece around the surface of a drum or cone while moving it upward or downward along this surface by means of a spiral track. As a result of this action, the surface is dried by an even distribution of dusting flour as well as by the dehydration occurring because of the exposure to the air, the gas cells near the surface of the ball are collapsed forming a thick layer which inhibits the diffusion of gases from the dough, and the dough piece assumes an approximately spherical shape. After this processing step, the dough ball passes to the intermediate proofer.

Types of Rounders

Rounders may conveniently be classified as bowl-, umbrella- or drum-type. The conical or bowl variety consists of a rotatable cone-shaped bowl around the interior of which is placed a stationary spiral track or "race." Fig. 92 schematically illustrates such a device, while Fig. 93 is a photograph of a commercially available machine. From the conveyor leading from the divider, the dough pieces fall into the feed hopper of the rounder and then drop to the bottom of the rotating bowl. The pieces are tumbled and rolled along the dough race until they emerge from the top of the bowl and fall onto the belt leading to the intermediate proofer.

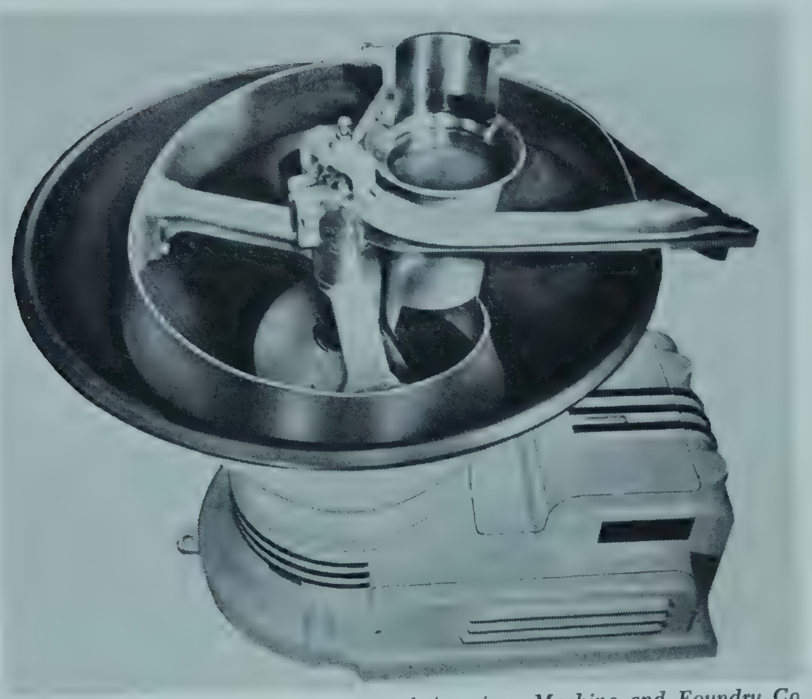
A second popular type of rounder is the so-called umbrella or inverted cone variety. These machines differ from the preceding kind in that the dough piece is carried around the outside surface of a cone which has its apex facing upwards. Fig. 94 is a photo of such a rounder. Since the dough enters the rounder at the larger diameter of the cone, as shown in the schematic diagram, Fig. 95, its initial movement is more rapid than it would be in the bowl rounder. Opinions vary as to the relative merit of the two types of machines. It is certain, however, that many examples of both types have been performing satisfactorily for many years.


DUSTER BOX
DUSTER ADJUSTMENT
DOUGH HOPPER FEED
CENTER SHAFT
DOUGH RACE
BOWL
DUSTER CONNECTING ROD
DUSTER ARM
UPPER BEARING
DUSTER ECCENTRIC
OIL LEVEL
ADJUSTABLE MOTOR BASE
DRIVE CHAIN
BOWL DRIVE WORM
BOWL DRIVE WORM GEAR
LOWER BEARING

Courtesy of Department of Defense

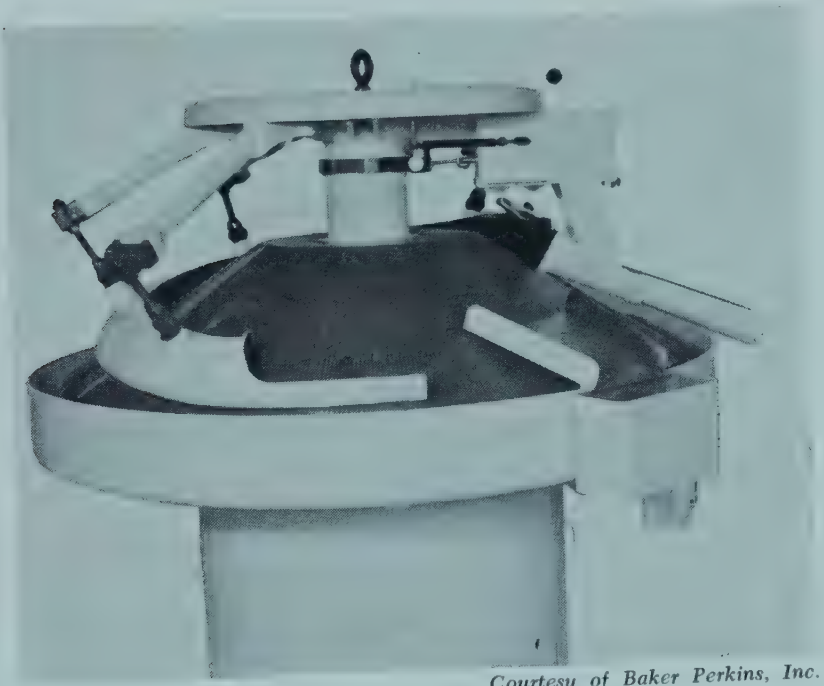
Fig. 92. Schematic Diagram of a Bowl-Type Rounder

A third type of rounder is the drum type. These machines differ from the bowl and umbrella varieties in that the cone segment has very little slope to its sides, i.e. the sides are almost vertical. The dough piece enters near the bottom of the drum. It is obvious that the ball travels at a more uniform rate in these machines than in the other two types. Among the advantages claimed for the drum rounders is that they require less



Courtesy of American Machine and Foundry Co.

FIG. 93. A COMMERCIALLY AVAILABLE BOWL-TYPE ROUNDER

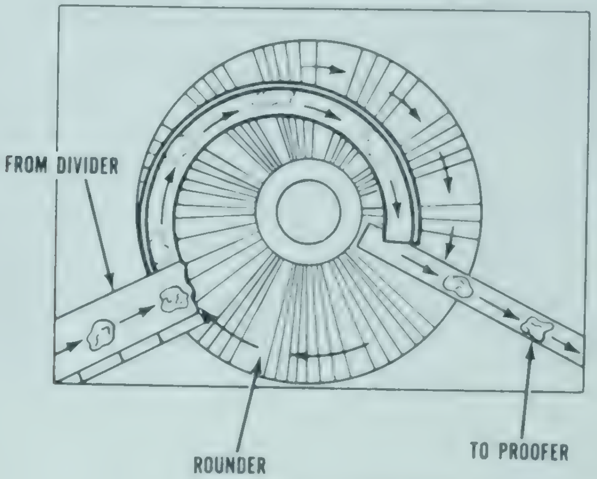


Courtesy of Baker Perkins, Inc.

FIG. 94. AN UMBRELLA-TYPE ROUNDER

floor space, allowing greater latitude in positioning the machine with respect to other make-up equipment. Fig. 96 illustrates positioning of the divider with respect to three different types of rounders.

A fourth style of rounder has concave sides. The round dough race is constructed in two or more sections on different planes. The dough pieces feed in at the top, move through the sections of the dough race, and are discharged into the feed drum of the intermediate proofer.



Courtesy of Department of Defense

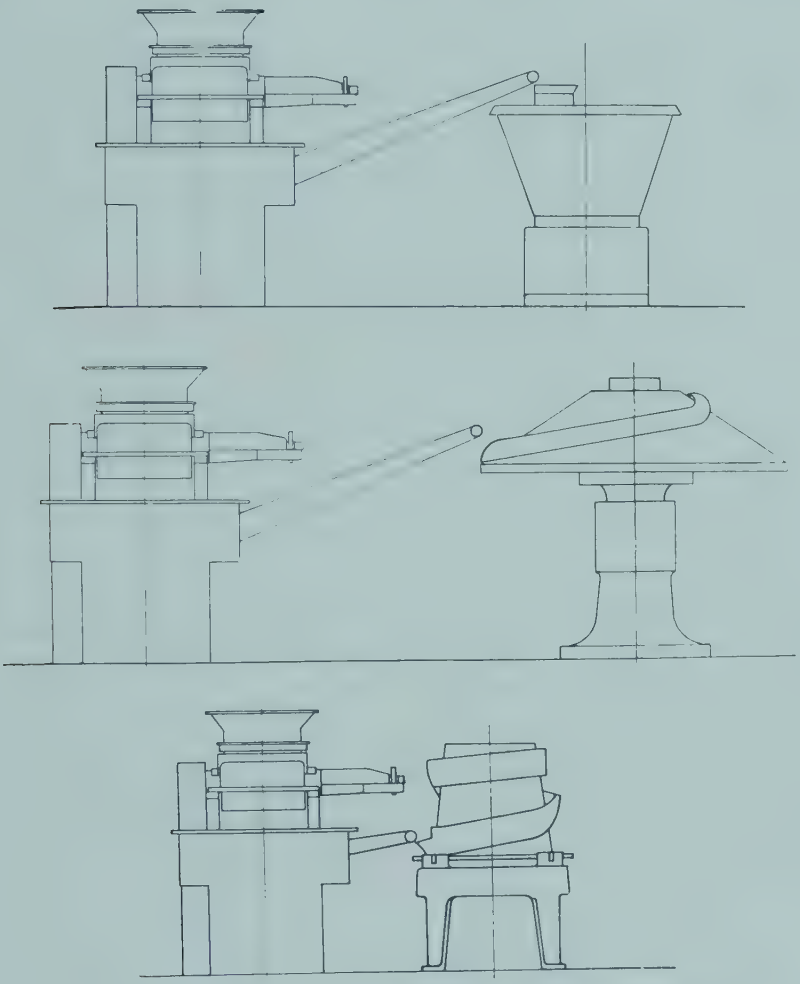
Fig. 95. Path of Dough Piece in an Umbrella-Type Rounder

In addition to their form, rounding machines may vary in the texture or composition of the rotating surface, in the means provided for adjusting the relationship of the dough race to the drum or cone, in the method of applying dusting flour, etc. The rotating surface is usually corrugated vertically or horizontally, but the design and size of the ribs varies considerably from one manufacturer to another. The surface may be waxed or it may be coated with a plastic such as Teflon to reduce sticking. Frequently, a device to shunt aside oversize dough pieces (doubles) is fixed at the exit chute.

Controlling and Adjusting the Rounder

Most rounders provide a means for adjusting the distance of the race from the rotating surface. This furnishes a method for controlling the formation of "pills" or small pieces of dough which are pinched off between the race edge and the drum. As a rule, the race should be just as close to the drum as it can be placed without creating friction. It should be recognized that a film of dough builds up as the rounder operates, reducing the amount of clearance between the race and the drum.

The speed at which the rounder rotates is usually not easily changed, a constant speed sufficing for all applications. The amount of dusting flour which the machine applies is capable of adjustment in most cases. Another important variable is the rate at which pieces are supplied to the rounder. Indications of a need for adjustment are the formation of doubles, tearing of dough pieces (usually due to an accumulation of dough film on the drum surface), cores in the finished loaves (too much dusting flour), and stick ups.



Courtesy of Dutchess Bakers' Machinery Corp.

FIG. 96. POSITIONING OF DOUGH DIVIDERS AND THREE DIFFERENT STYLES OF ROUNDERS

Maintenance requirements for rounders are relatively simple and consist fundamentally of proper lubrication and adequate cleaning. Dusting flour accumulations should be removed at every convenient opportunity. Accumulations of dry dough on the cone surface are particularly harmful and should be carefully removed during each shutdown. To avoid scoring the surface, hardwood or plastic scrapers should be used. If special maintenance procedures are necessary for any machine, the manufacturers service booklet will list them.

Rounders are inherently less dangerous to operate than are dividers and moulders, nonetheless an occasional operator will find some ingenious way to get a finger or hand caught in the mechanism. As in the case of all other machines involving moving parts, the operator should be directed to keep his hands away from shear points and pinch points and to assure himself that the power will remain off while he is cleaning the device.

INTERMEDIATE PROOFERS

Function of the Intermediate Proofer

When the dough piece leaves the rounder, it is rather well de-gassed as a result of the punishment it received in that machine and in the divider. The dough lacks extensibility and tears easily. It is rubbery and would not mould satisfactorily. To restore a more flexible, pliable structure which will respond well to the manipulations of the moulder, it is necessary to let the dough piece rest while fermentation proceeds. This is accomplished by letting the dough ball travel through an inclosed cabinet for a few minutes. The physical changes other than gas accumulation which occur during this period are rather obscure, but apparently there are some alterations in the sub-microscopic structure of the dough which render it more responsive to the subsequent operations. When the dough leaves the intermediate proofer, it is found to be larger in volume due to gas accumulation, the skin is firmer and drier, and the piece is more pliable and extensible.

Types of Intermediate Proofers

Most intermediate proofers used at the present time are the overhead type in which the principal part of the cabinet is raised high enough above the floor to allow space for other make-up machinery beneath it. When overhead space is not adequate, one of the floor types may be installed.

Intermediate proofers may be conveniently divided into the belt type and the tray type, the latter variety having many sub-types. The former style consists essentially of endless belts running in a closed cabinet. The dough pieces are carried forward to the end of the cabinet, then dropped down on the next lower belt traveling in the opposite direction, and so on until they reach the exit conveyor. Fig. 97 illustrates the principles of operation of such a machine.

Tray-type conveyors, and in this class are included all conveyors which have segmented areas for carrying dough pieces, are composed of equipment which moves the dough in metal pans, troughs or buckets, wooden trays, or canvas loops. Fig. 98 illustrates schematically an overhead tray type proofer which has perforated metal troughs or tubes in which the dough pieces are dropped. Each of the types has its special virtues and evils and consequently has proponents and detractors. Attributes of the dough carrying unit which are of importance in evaluating the relative worth of an intermediate proofer are: (1) The ease of cleaning and of

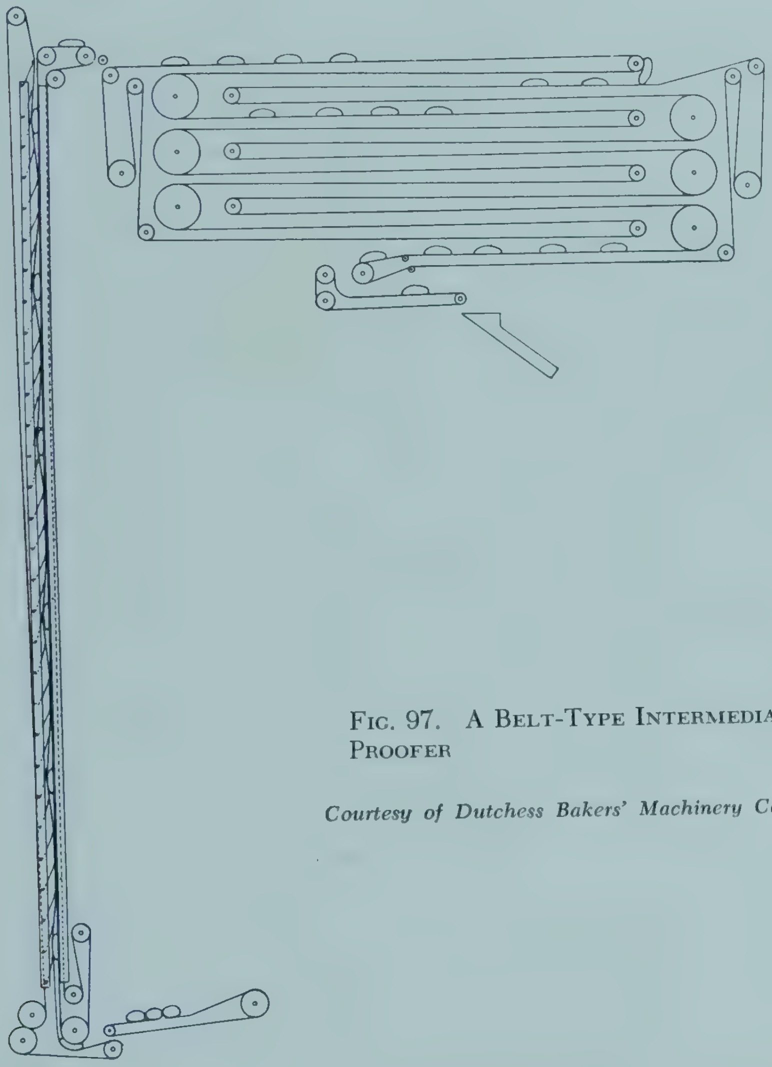
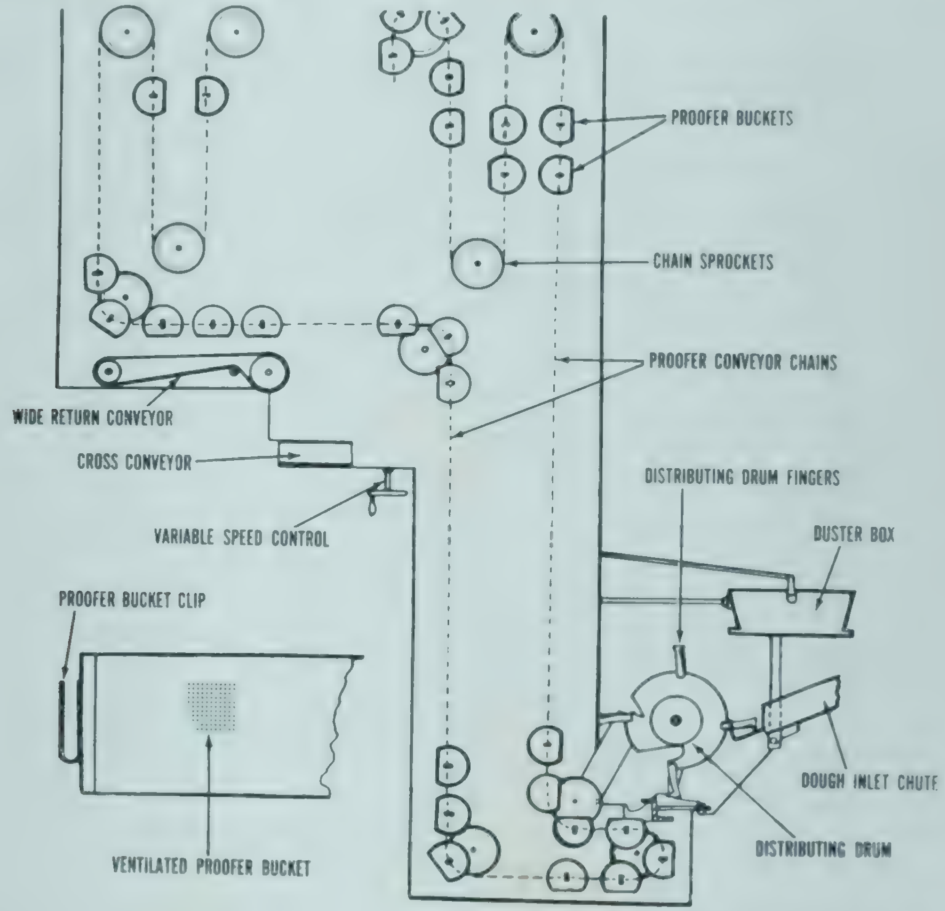


FIG. 97. A BELT-TYPE INTERMEDIATE PROOFER

Courtesy of Dutchess Bakers' Machinery Corp.

keeping it clean; (2) ease of replacement and economy of repair, and (3) its adequacy in preventing doubles and retaining the proper form of the dough piece.

Fig. 99 illustrates a tray type of intermediate proofer which uses canvas loops over metal frames as the carrying means. Location of overhead proofers of this, and other types, must be carefully planned. They should be easily accessible from all sides for cleaning and maintenance. The foundation should be level and capable of giving a firm base to the proofer. They should not interfere with free movement of personnel beneath or around them, or with placement and function of other make-up equipment.


PROOFER BUCKETS
CHAIN SPROCKETS
PROOFER CONVEYOR CHAINS
WIDE RETURN CONVEYOR
CROSS CONVEYOR
DISTRIBUTING DRUM FINGERS
DUSTER BOX
VARIABLE SPEED CONTROL
PROOFER BUCKET CLIP
DOUGH INLET CHUTE
DISTRIBUTING DRUM
VENTILATED PROOFER BUCKET

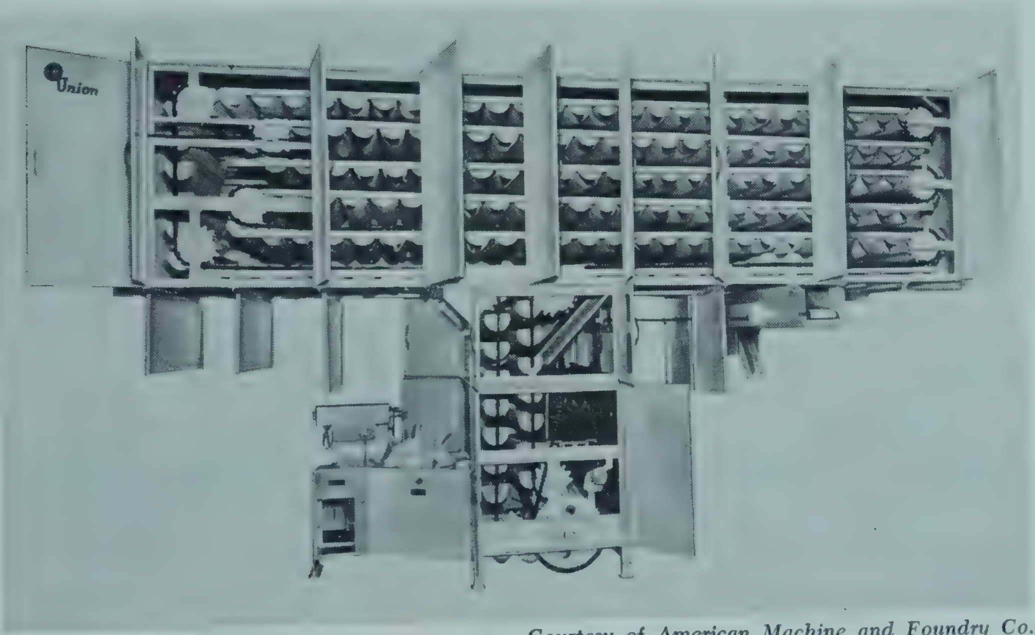
Courtesy of Department of Defense

FIG. 98. DIAGRAM OF A TRAY-TYPE INTERMEDIATE PROOFER SHOWING LOADING MECHANISM

An important part of the intermediate proofer is its loading mechanism. This machinery takes the dough pieces which come along the conveyor belt in single file, and arranges them in rows in the receptacle of the intermediate proofer. The proofer trays may contain spaces for 2 to 8 dough pieces placed across the tray.

Controlling and Adjusting the Intermediate Proofer

Intermediate proofers of all types are equipped with variable speed controls which can be used to determine the length of time dough pieces spend within the cabinet. An absolute maximum of dwell time is dictated by the maximum capacity of the proofer and the rate of output of the divider and rounder. If an attempt is made to slow the machine below this point, doubles will accumulate in the dough pockets or on the belts. Below this maximum level of capacity, the correct time for the dough piece to stay within the cabinet is determined by the period necessary to condition the dough properly.



Courtesy of American Machine and Foundry Co.

FIG. 99. OVERHEAD INTERMEDIATE PROOFER USING CANVAS LOOPS OVER METAL FRAMES AS THE CARRYING MEANS

No large capacity (over 3,000 lbs./hr.) intermediate proofers are available with air conditioning equipment built in. Temperature and relative humidity are thus at the mercy of room conditions and the state of the dough pieces entering the proofer. Fortunately, an absolutely uniform and carefully controlled treatment at this stage is not essential for the dough. A moderate range of variation can be tolerated without causing significant observable differences in the finished loaf. Since room conditions usually remain fairly constant over extended periods, and since the temperature and equilibrium relative humidity of the dough do not usually vary a great deal, the former being largely determined by the temperature in the fermentation room and the latter by dough composition, insuperable difficulties in adjusting the intermediate proofer seldom occur. It is certainly desirable to have means for controlling the temperature and relative humidity of the interior of the intermediate proofer, however. Some modern cabinets of relatively low capacity do have air conditioning units, or provision for ventilating with air from an outside source. Others could be improved by the addition of steam outlets to provide additional moisture. Opening the doors of the cabinet to reduce the humidity or temperature is inadvisable because it creates drafts with resultant erratic behavior of the dough pieces, e.g. crusting, insufficient proof, etc.

Maintenance of intermediate proofers is a matter of keeping the machine cleaned and lubricated. The pockets or belts accumulate coatings of dusting flour and dough and must be cleaned frequently. This process requires removal of the trays, buckets, or belts, and thorough washing of them. The schedule for cleaning is dependent upon the climate, the susceptibility to infestation of the plant, and other factors.

The Baking Industry Sanitation Standards Committee has enunciated the following general principles of design and construction for mechanical (intermediate) proofers:

"**Product Zone**

(1) All surfaces in contact with the dough piece shall be impervious to flour, dough and resist the effect of the acids and other products of dough fermentation, and capable of being readily cleaned and sanitized. This shall not apply to fabric liners or belts that can be removed for cleaning.

(2) All surfaces shall be smooth, of non-toxic material and free from loose scale, pits, cracks, crevices, and other imperfections and not contain stampings or embossings.

(3) All surfaces and areas within the product zone should be readily accessible to both sight and reach.

(4) All inside corners and intersections, other than in parts that can be readily removed for cleaning, shall be rounded or cone shaped, with not less than one-sixteenth inch minimum radius of curvature, to minimize retention of flour, dust or other material.

(5) Set screws, keys and/or other projections, also inside threads, tapped holes, keyways, sockets or other recesses, should be avoided. Nuts shall not be placed so as to form pocket patterns.

(6) All product zone enclosures shall be so designed that they may be readily opened for inspection and cleaning, and reclosed securely with a minimum of time, with fewest possible loose parts, and by use of only simple tools.

(7) Solder shall contain not more than 5 per cent lead and other toxic material. Silver solder, consisting mainly of silver, copper and zinc, shall not contain cadmium or other toxic materials.

(8) When sheets or plates are permanently joined they should preferably be butt welded with the welds ground smooth in the product zone. If horizontal lap joints are necessary the upper sheet shall lap over the lower sheet. All lapped joints shall be scarfed and the joint filled and smoothed.

(9) Bearings shall be of the sealed or self lubricating type wherever possible. If the bearings cannot be removed for cleaning, they should be pressed into the housing and sealed to prevent flour from seeping into the space between the bearing and the housing. Where it is possible, the bearings shall be out-board. Where lubrication is required, the design and construction shall be such that lubricants cannot leak, drip, or be forced into the product zone."

"Non-Product Zone

(1) All bolt heads and nuts shall be set so that they do not form pocket patterns or areas hard to reach for cleaning.

(2) Housing or guards around sprockets, chains, shafts, pulleys, etc., shall be removable, or be fitted with easily removable covers to provide for access and cleaning. These may be fitted with hinges.

(3) All joints and edges where two members are permanently joined or lapped shall be properly filled, welded, or smoothed to prevent cracks or recesses that may retain flour and dust, or harbor contamination.

(4) All surfaces shall be accessible to both sight and reach.

(5) Metal or other non-absorbent, odorless, non-splinterable material shall be used.

(6) Hinges shall be of the loose pin or take apart type and shall not contain cracks and crevices that cannot be cleaned.

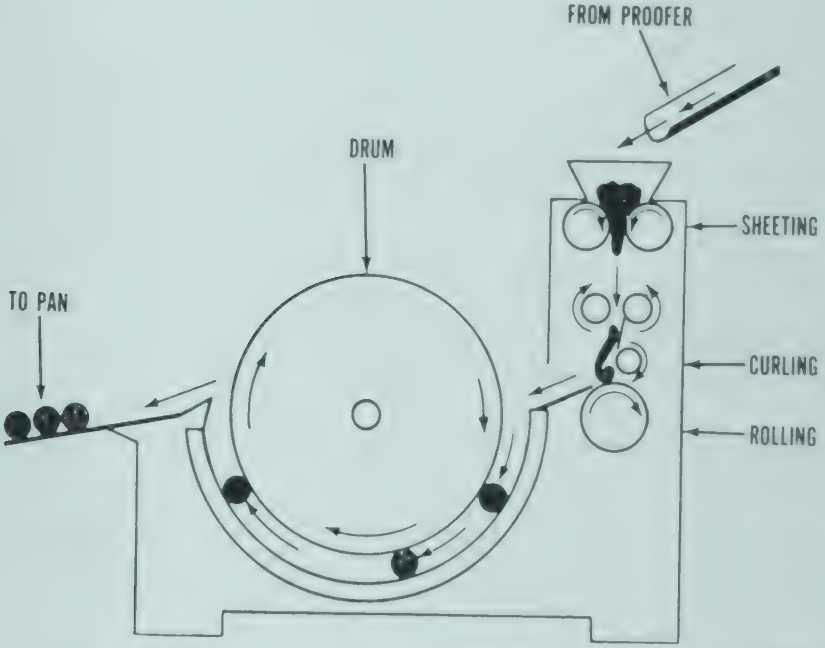
(7) Surfaces shall be reasonably smooth with castings free of coarse sand impressions or blow holes. The base frames and supporting members shall be designed to be cleaned easily and shall be free of pockets, crevices and other inaccessible spaces where flour may collect or insects develop."

MOULDERS

Function of the Moulder

In the bread-making plant, the moulder receives pieces of dough from the intermediate proofer and shapes them into cylinders (loaves) ready to be placed in the pans. There are several types of moulders, each of which will be described later, but they all have four functions in common: sheeting, curling, rolling, and sealing. Some writers consider the last two as one function, since they are performed simultaneously. Fig. 100 is a schematic diagram of a simple type of moulder in which these functions are illustrated. The dough as it comes from the intermediate proofer is a flattened spheroid.

The first operation of the moulder is to flatten this spheroid out still more into a thick sheet which can be properly manipulated in the later stages of moulder operation. This effect is usually achieved by two or more (usually three) consecutive pairs of rollers, each succeeding pair being set more closely together than the ones which precede it. The first pair of rolls, called the head rolls, exerts only a relatively slight pressure on the dough piece. The second set of rolls, the center rolls, operate at an intermediate pressure. The last set, which may be called either the sheeting rolls or the lower rolls, exerts the maximum pressure on the dough sheet. In the case of a reverse sheeting moulder, there are two single rolls, the reversing roll and the receiving roll, which intervene between the center rolls and the lower rolls. The gradual reduction in thickness effected by this multiple roller system minimizes the punishment received by the dough, so that tearing and similar problems are reduced. Sometimes a single "flattening" roll is located above the infeed conveyor to the moulder. The flattening roll performs an initial slight reduction in thickness of the dough piece which facilitates its engagement by the first pair of rolls.



Courtesy of Department of Defense

FIG. 100. DIAGRAM OF A SIMPLE TYPE OF DRUM MOULDER

In the past few years, it has become fairly common to encase the sheeting rolls with Teflon sleeves in order to render them resistant to adhesion to the dough pieces. When the moulder sheeting rolls have not been treated in this manner, scrapers are placed so as to assure the separation of the dough sheet from the rollers.

After the dough has been sheeted out, it is curled up into a loose cylinder. This operation is conventionally performed by a special set of rolls, as indicated in Fig. 100. Alternately, it is accomplished by a pair of canvas belts. The lower conveyor belt moves the dough piece forward until the upper curling belt or mat engages the front end of the piece, brings it back, and curls it up into a loose cylinder. A more advanced development substitutes a short length of woven metal mat or linked thin metal bars for the upper curling belt. In these machines, the metal curling device is affixed just above the conveyor belt, with one end resting on the belt. As the dough piece passes under the curling device, the weight of the latter creates enough drag to pull the forward end of the dough piece up and retain it while the conveyor belt rolls the piece into a cylinder.

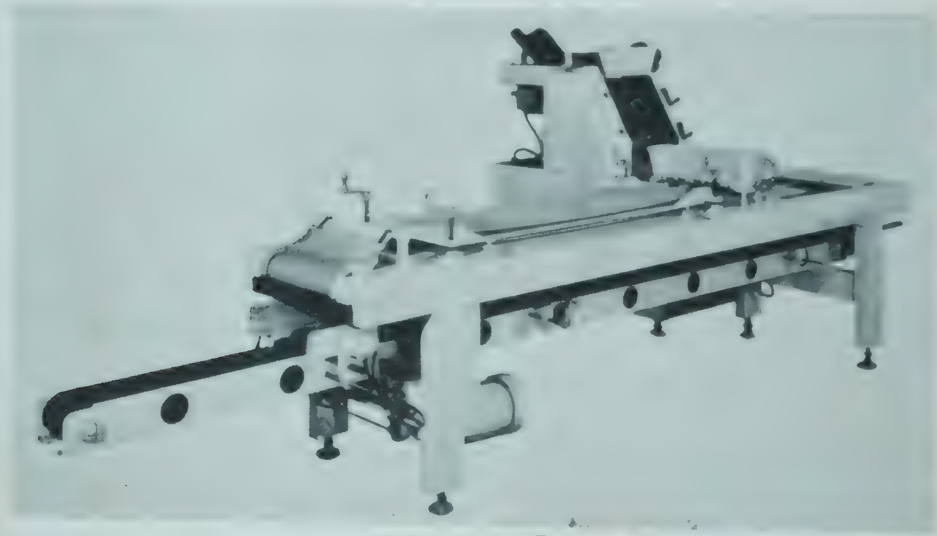
The layers in the cylinder of dough are not tightly adherent when it leaves the curling section. The next function of the moulder is to seal thoroughly the dough piece so that it will expand into the typical loaf shape when it is proofed. In addition the cylinder of dough is lengthened so that its axial dimension is somewhat greater than the length of the pan, and entrapped air between the dough layers is expelled. The conventional moulder achieves these results by rolling the dough cylinder between a large drum surfaced with canvas and a semi-circular compression board having a smooth surface. Clearance between the drum and board is gradually reduced along the route of dough travel so that the piece is constantly in contact with both surfaces and gradually becomes compressed.

An integral component of most modern moulders is the automatic panning device. The empty pans are carried by a conveyor past the end of the moulder, and the loaves are transferred from the moulder and positioned in the pans by an apparatus operated by compressed air.

Types of Moulders

As the dough piece passes through the sheeting rolls, there is a tendency for the moisture content of the trailing edge to become increased at the expense of the leading sections. This redistribution of moisture results from the effect of compression on the dough structure. In the normal course of events in a conventional moulder, the trailing edge, which is of relatively high moisture content, ends up as the outside layer of the cylinder. It has been thought for many years that it would be preferable, from the standpoint of loaf performance during proofing and baking, to have the wetter portion of the dough sheet folded into the center of the loaf. Observations on hand moulded doughs formed in his manner seemed to confirm the superiority of "reverse moulded loaves."

The major modifications which have been made in moulder design in the last few years are the result of attempts to avoid folding the dry end of the dough sheet into the center of the loaf. Successful developments have included the cross grain moulder and the reverse sheeting moulder. The former type curls the dough sheet at right angles to its direction of travel through the sheeter rolls. As a result, the wetter edge of the dough forms one end of the loaf rather than the outside layer. The cross over effect is achieved by changing the direction of travel of the dough 90 degrees after it leaves the sheeting rolls. According to Hunter (1949), the first machines developed used a turnover or "flip-flop" method of transfer, while a slide transfer or "shoot-over" method later came into use. Fig. 101 illustrates a cross-grain moulder-panner which uses the slide transfer system.

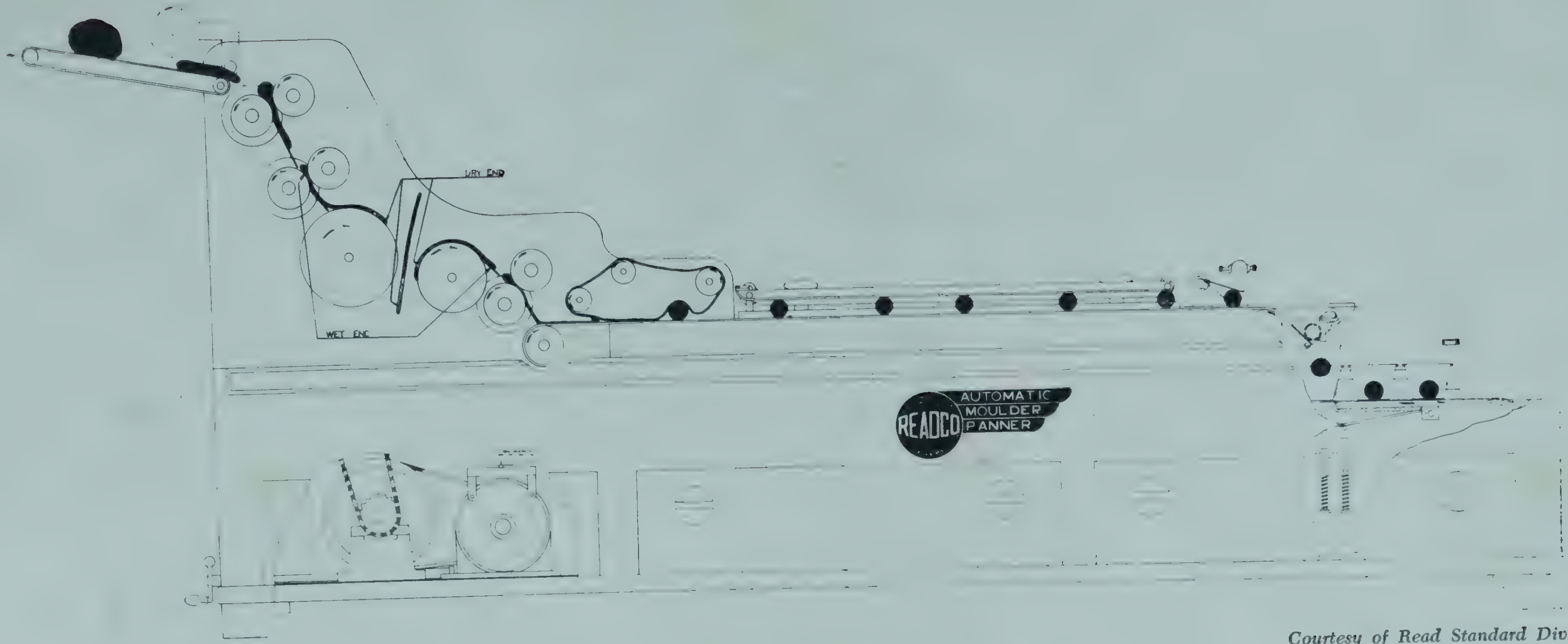


Courtesy of Stickelber and Sons, Inc.

Fig. 101. Cross-Grain Moulder-Panner

The reverse sheeting moulder was devised to curl the sheet of dough so that the wet end of the piece would be folded into the center of the loaf. The dough piece is turned over or reversed between the second or third set of rolls (between the center rolls and the sheeting rolls) thus placing the original trailing end (or wet end) in the leading position. Figure 102 is a diagram of a moulder-panner which includes these operations.

Another type of moulder that was developed primarily to give loaves with more uniform cell structure twists the dough pieces after they have been rolled into cylinders. Twist bread has been very popular in some sections of the country for many years. The twisting was formerly done entirely by hand, an obviously uneconomical practice in this highly competitive industry. Machines are now available which will perform the twisting at a rapid rate and with results as good or better than those achieved by hand twisting. Fig. 103 illustrates a combination moulder


DRY END
WET END
READCO
AUTOMATIC
MOULDER
PANNER

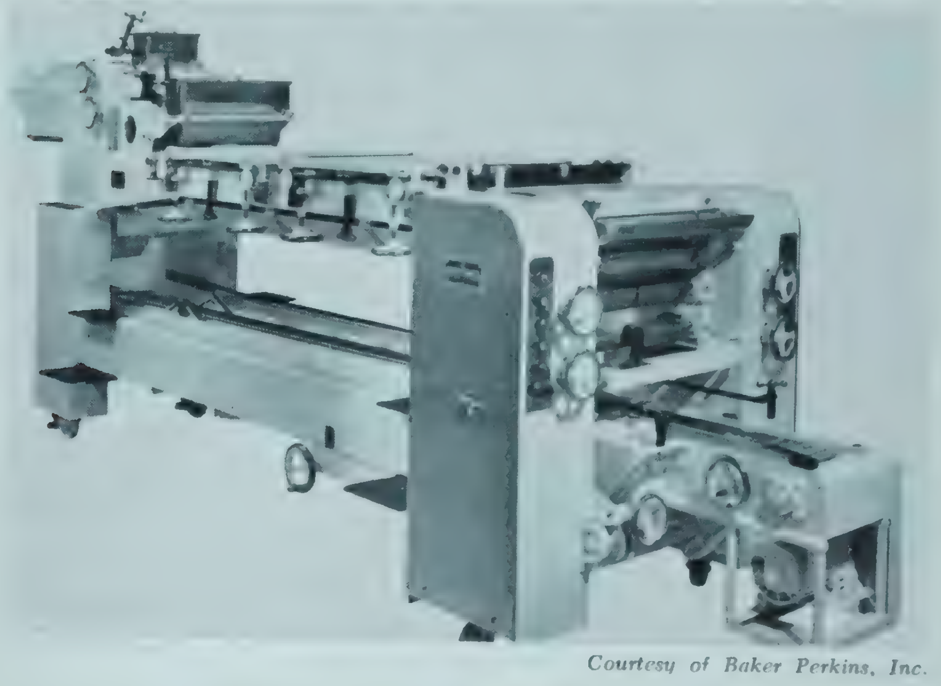
Courtesy of Read Standard Div.

FIG. 102. DIAGRAM OF A REVERSE-SHEETING MOULDER-PANNER

twister-panner. The dough cylinder falls into the U-shaped cups shown at the right end of the machine and then is twisted by a rotary movement of the cups.

Controlling and Adjusting the Moulder

The first adjustment (in terms of sequence of the processing) possible on the moulder is the setting of the head rolls. According to Mohr (1949), most steel head rolls are run with an opening of 0.140 to 0.180 in. With plastic covered sheeting rolls of equivalent size, it is possible to reduce the opening to 0.060 in. Many authorities seem to feel that the closer these rolls can be set without tearing the dough, the better will be the grain in the finished loaf. In any case, the optimum setting will be determined by the conditions existing in each particular plant. It is evident that the lower sets of rolls should be set more closely than the upper set, and that the difference between the first pairs should be greater than the difference in settings of the last two pairs.



Courtesy of Baker Perkins, Inc.

FIG. 103. A MOULDER-TWISTER-PANNER

Adjustment of the scrapers on the head rolls (if plastic covered rolls are not used) should be just sufficient to prevent stick ups. Too close settings create friction and may even result in scoring of the roll surface.

The speed of the moulder can be adjusted, and should be sufficient to allow adequate space between the dough pieces arriving from the intermediate proofer.

The length of the dough cylinder discharged from the moulder is governed by adjusting rails or guides lying between the compression surfaces. These guides should be far enough apart so that the dough piece is just slightly longer than the pan.

Clearance between the compression surfaces is another variable which can be controlled in moulders. Enough pressure should be exerted on the piece to seal thoroughly the contacting layers of dough. Too much pressure will result in dumbbell shaped pieces and consequent misshapen loaves of bread. Too little pressure, in addition to causing inadequate seals with holes in the bread, may give dough pieces of oval longitudinal section which bake into misshapen loaves. Gradual application of pressure is necessary to efficiently remove air bubbles from between the dough layers.

Dusting flour applicators should be controlled to give the minimum rate of addition consistent with the prevention of stick ups and other malfunctioning of the machinery. Too much flour added at this critical stage will result in spots and streaks in the bread, holes due to poor sealing, and other defects.

Maintenance requirements include lubrication of the mechanical parts, cleaning away dough particles and flour from the working surfaces, and application of divider oil to the rolls after cleaning.

The moulder is a relatively hazardous piece of equipment. The American Standard Safety Code for Bakery (Anon. 1947) establishes the following requirements for safe operation of the moulder:

> "(1) **Hoppers.**—Mechanical feed moulders shall be provided with hoppers so designed and connected to the proofer that an employee's hands cannot get into the hopper where they will come in contact with the in-running rolls.
>
> (2) **Hand-Fed Moulders.**—Hand-fed moulders shall be provided with a belt-feed device or the hopper shall be extended high enough so that the hands of the operator cannot get into the feed rolls. The top edge of such a hopper shall be well rounded to prevent injury when it is struck or bumped by the employee's hand.
>
> (3) **Stopping Devices.**—There shall be a stopping device within easy reach of the operator who feeds the moulder and another stopping device within the reach of the employee taking dough away from the moulder.
>
> (4) **Clean-Out Holes.**—Machines shall be so designed that there is no shear point in close proximity to the clean-out holes.
>
> (5) **Rear of Moulders.**—At the rear of moulders all revolving shafts shall have round corners or cylindrical surfaces, and all bolts shall be flush. Tie rods shall be far enough from revolving parts to prevent a shearing or pinching hazard.
>
> (6) **Adjustment Crank.**—Where a removable crank is used to adjust the moulder for different sizes of loaf, brackets shall be provided on the side of the machine for holding the crank when it is not in use. The brackets should be connected to a limit switch so that when the crank is removed the current

is broken and the machine cannot run unless the crank is returned to the resting position on the machine."

The Code brings out the following additional points about safe practices in moulder operations:

"(a) Where the moulder is designed for direct feed from proofers a few pieces of dough at the end of the run are frequently fed into the hopper by hand The hopper being designed for mechanical feed does not give the necessary protection for hand feed. In such cases it is recommended that the dough pieces be dropped on the in-feed conveyor.

(b) During hand-feed operations dough is apt to be sticky and cling to the operator's fingers. It is, therefore, much easier for the operator, if he is able to throw the dough into a hopper that is deep enough and has a rounded edge which will allow him to hit the hopper regularly with each stroke of his hand thereby releasing the sticky dough.

(c) Some moulders have been installed so that the delivery end is at the wrong elevation. The operators have to stoop in order to pick up the dough and this is very fatiguing. It has been suggested that all installations should be so arranged that the delivery point is 35 inches above the floor."

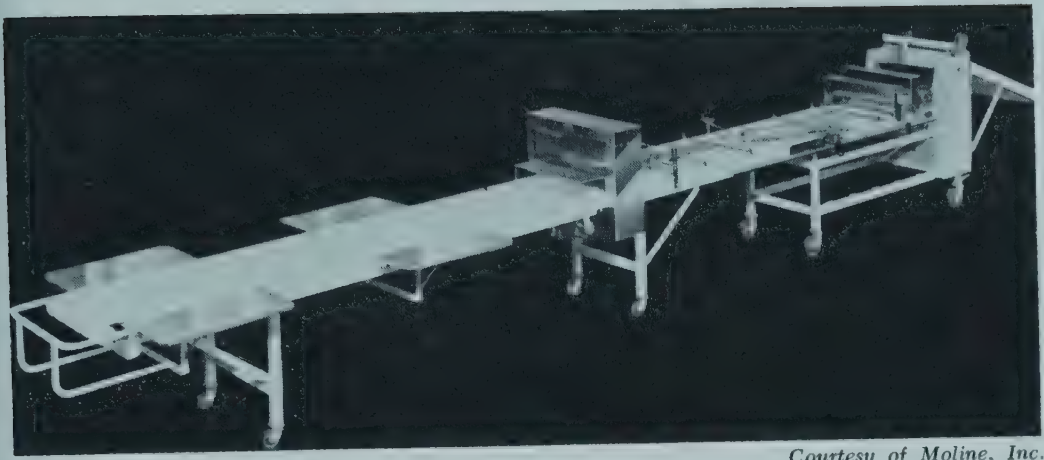
SPECIAL MOULDING AND FORMING MACHINES

Sweet Goods

Dough brakes for sheeting out sweet doughs have been used for many years. In principle these are quite simple, being a set of long horizontal steel cylinders having adjustable clearance. A set of plates or chutes are provided for guiding the dough into and out of the rolls. Usually, the brakes include automatic return devices which bring the dough back into the hands of the operator. In recent years, more of the hand operations required in making sweet yeast-leavened goods have been mechanized by ingenious and efficient devices. Fig. 104 illustrates a machine which automatically sheets the dough, applies liquid and solid flavoring agents, rolls the sheet into an endless helical coil, seals the dough piece, and cuts it into the desired shape. Several firms offer machines which perform many of the same functions and operate on the same principles.

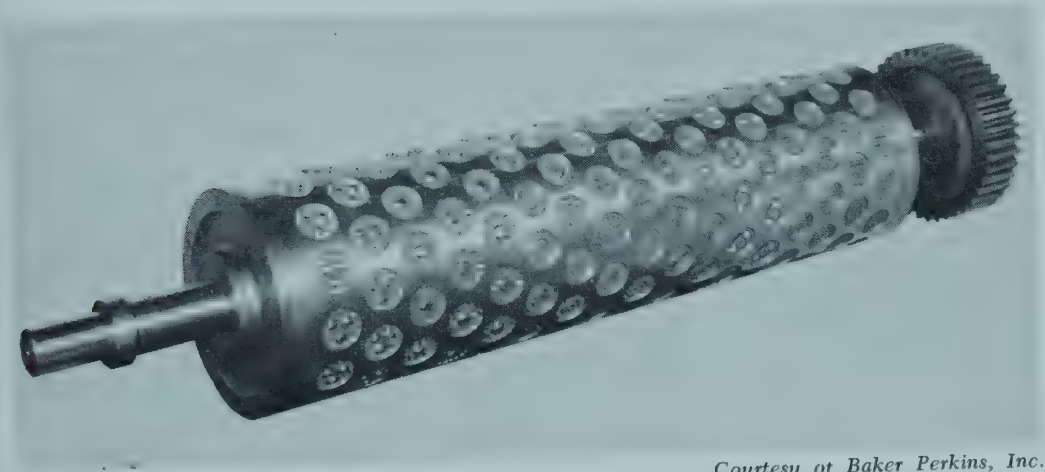
Cookies

Cookies are formed by two major types of process, a die-forming procedure or an extrusion procedure. The latter may be a complex process such as that used in making fig bars, in which an endless casing of dough is extruded around a center extrusion of fig jam, or it may be a simple procedure such as those used in making deposited or drop type cookies, of which vanilla wafers, chocolate chip, oatmeal, and similar varieties are representative. The principles in each case are the same, i.e. pressure is applied to a reservoir of dough to force strands of it through an orifice



Courtesy of Moline, Inc.

FIG. 104. A MECHANICAL BENCH FOR SWEET GOODS PRODUCTION



Courtesy of Baker Perkins, Inc.

FIG. 105. AN EMBOSSED MOULDING ROLL FOR COOKIES

The opening may be circular or fancy in shape. The dough strand is cut into cookie size pieces by slicing devices reciprocated across the orifice, or, as in the case of fig bars, by slicing discs running across the lines of baked cookies as they exit from the band oven.

Cookies produced on rotary moulders include sandwich types and all of those with embossed designs. A steel cylinder whose surface is covered by engraved pockets rotates past the opening in a hopper filled with cookie dough. The pockets are filled with the dough which is sheared off from the main mass as the cylinder completes its revolution and the dough pieces are ejected on to a conveyor belt leading to the band oven. Fig. 105 is a photo of an embossed cylinder used in cookie production.

Sugar wafer bases are formed on a large griddle-like mold. A very thin batter is flowed on to the hot (steam-heated) mold and the top is then pressed down for a short time. The crisp wafer is manually removed from the mold.

Many types of depositors, enrobers, etc. are available for applying the fillings, coatings, and similar adjuncts to cookies but there is not sufficient space to discuss them here.

Soda crackers, club crackers, saltines and like varieties are formed by a reciprocating cutting machine which divides an extruded sheet of dough. In addition, crackers are "docked" or perforated by pins in order that the cracker will retain its flat shape during baking.

CONCLUSION

Summary

In the preceding discussion, each machine in the make-up complex has been considered in the sequence in which it appears in the processing line. The dough is changed by these machines from a formless mass filled with gas bubbles of greatly varying size to a cylindrical piece of loaf size having small vacuoles well suited to yielding a uniform grain in the finished loaf. The importance of integrating speeds to secure maximum efficiency has been emphasized, and the difficulty of predicting the exact treatment which will yield optimum results under the unique conditions existing in each bakery has been pointed out. Certain constant factors which are more or less independent of the variations in conditions from plant to plant were listed for each device.

Future

It is clear enough that the trend for the last couple of decades has been in the direction of reducing human effort in the manufacture of bakery foods. The arduous, inefficient, and error-prone manual operations of the past are being supplanted at a steadily increasing pace by automatically controlled devices. As this trend progresses and extends itself into other, more complex processing steps, the bakery artisan will find his place taken by the engineer and the cereal scientist who are able to quantitate those factors with which he has had to deal intuitively. Cheapening of production costs on a quantity basis will increase the pressure against the small retail baker who cannot afford to automate his plant. The small shop owner who recognizes that his chance for survival lies in the manufacture of specialty items having a limited but high-priced market will prosper, while he who attempts to compete on the bread market or in similar lines will suffer the usual consequences of folly.

There is little doubt that many or all of the bread forming devices which have been described in this chapter will eventually be replaced by some variety of continuous processing apparatus controlled by feedback methods, although there is no intention to imply that this change will occur even within the next decade or two. A close examination will show us that economic pressures, labor problems, and the opportunity for better product control will eventually force these changes no matter how much tradition and sentiment incline us to the opposite view.

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Hugh K. Parker

Continuous Bread Making Processes

The oldest bakers in the trade today will no doubt recall expressing hope or expectation that their laborious efforts would some day be replaced or improved upon by some revolutionary mechanical means of producing a loaf of bread. Step by step these dreams have evolved into such realities as mechanical mixers, traveling ovens, mechanical dividing and molding, and on to the fully automatic modern large-scale bakery of today.

In some modern bakeries the make-up equipment before the doughs enter the proof box has undergone rather drastic changes within the past few years. In 1953 My Bread Baking Company at New Bedford, Massachusetts, installed a continuous bread-making process for preparing white pan bread at the rate of about 60 one-pound loaves per minute. After about a year of experimental operation, the process was put into full scale operation and has been in constant and expanding production. By the end of 1959, 59 units were in operation. This process has the trade name "John C. Baker Do-Maker" and is marketed by the Baker Process Company, a Division of Wallace & Tiernan, Incorporated, of Belleville, New Jersey. Dr. John C. Baker is the inventor of the Do-Maker Process. As a point of human interest, it can be said that the development and final acceptance of the process is the culmination of Dr. Baker's dreams and researches that cover a period of years. Dr. Baker (1954) described his process at the Thirtieth Annual Meeting of the American Society of Bakery Engineers (see Fig. 106).

Another continuous process has been in operation at the Fischer Baking Company in Asbury Park, New Jersey, for some time—experimentally at first and then on full commercial scale in 1959. This is the AmFlow process of the American Machine and Foundry Company in New York, and has been described by Cronen (1959) in some detail (see Fig. 107).

Both the Do-Maker and the AmFlow processes are designed to feed continuously the necessary ingredients of the baker's formula to a mixing device. The ingredients are thoroughly mixed together to a homogenous mass and passed on to a dough pump, where the rate of dough flow is regulated and the dough then delivered to a developing apparatus. In the developer kneading work is done on the dough, so that proper structure and gas retention properties for subsequent processing result. The developed dough is moved out of the developer to an at-

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Hugh K. Parker is a consultant to the food industries.

tached piece of equipment which divides and continuously extrudes the shaped dough of proper weight into pans moving below. The pans are moved in synchronization with the cutting knives of the divider, so that each piece of dough is properly placed in the pan and is ready for the proof. The mechanical details of the two processes are different and some differences may be noted in the end result, but this general description is for the purpose of illustration and indicates continuity in both processes.

Figs. 106 and 107 are intended to show the overall processing from ingredient addition to the deposit of the shaped dough piece into pans moving to the proof. It should be remembered that the ultimate in continuous processing is to produce a uniformly well risen, beautifully textured bread of good flavor.

The purpose of this chapter is to discuss and describe these most recent additions and improvements and to show how these fit into present day big scale operation. The discussion will begin with the preparation of typical white panned bread in the United States as produced by continuous processes. The formulas used have some range in respect to choice and amounts of ingredients used, and in general are not too different from conventional formulas. Some ingredients contribute flavor over and above fermentation effects, which are necessary for good bread. Table 72 has been drawn up to list ingredients and remarks follow to explain certain functional effects.

Table 72

FORMULA RANGE FOR CONTINUOUS PROCESS BREAD

Flour	100 lbs.	Milk	$1^{1}/_{2}$ to 6 lbs.
Water	as required	Yeast Food	4 to 8 oz.
Salt	$1^{3}/_{4}$ to $2^{1}/_{4}$ lbs.	Vitamin Tablet	1
Yeast	2 to 3 lbs.	Calcium acid phosphate[1]	0 to 4 oz.
Sugar	6 to 12 lbs.	Mold inhibitor[1]	0 to 5 oz.
Shortening (mono-, diglycerides[1])	$1^{1}/_{2}$ to 3 lbs.	Bromate and iodate	

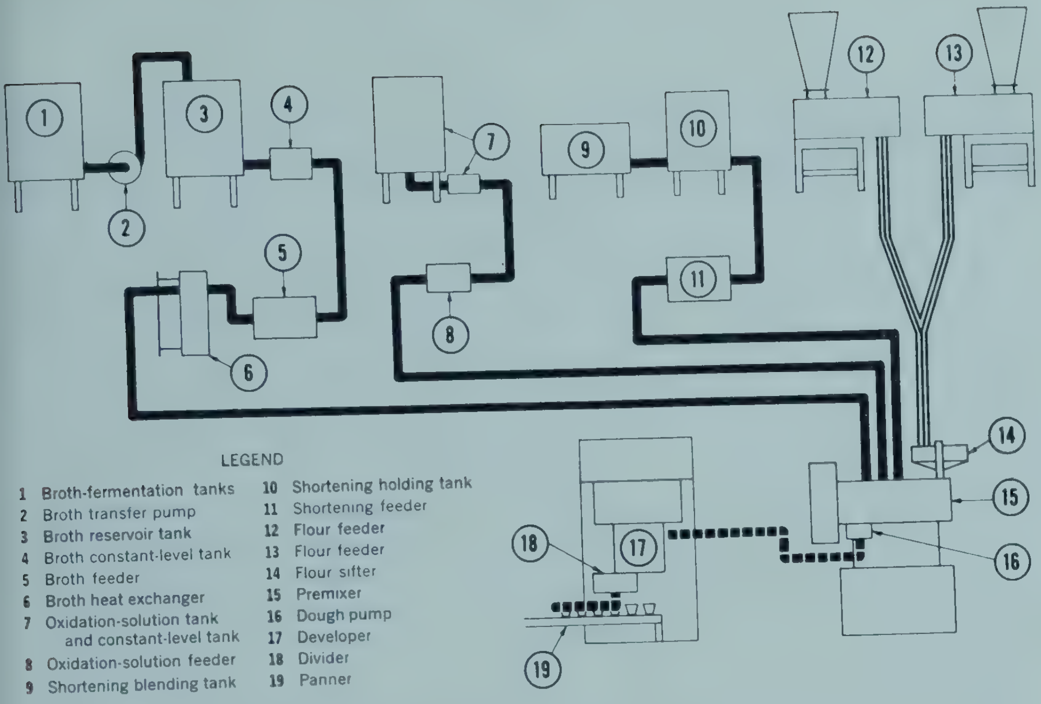
[1] Optional ingredients.

Ingredients

Yeast.—As described above, is more or less the standard type of compressed yeast. Active dry yeast can also be used if the manufacturer's instructions are carefully followed.

Sugar.—Either sucrose (cane or beet sugar) or dextrose can be used for carbohydrate fermentation. Sweetness in bread can be controlled by the amount of sugar remaining after fermentation.

Shortening.—Lard or hydrogenated vegetable materials can be used. The shortening usually also carries the so-called softeners such as mono-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LEGEND
1 Broth-fermentation tanks
2 Broth transfer pump
3 Broth reservoir tank
4 Broth constant-level tank
5 Broth feeder
6 Broth heat exchanger
7 Oxidation-solution tank and constant-level tank
8 Oxidation-solution feeder
9 Shortening blending tank
10 Shortening holding tank
11 Shortening feeder
12 Flour feeder
13 Flour feeder
14 Flour sifter
15 Premixer
16 Dough pump
17 Developer
18 Divider
19 Panner

Fig. 106. Flow Sheet of the Do-Maker Process

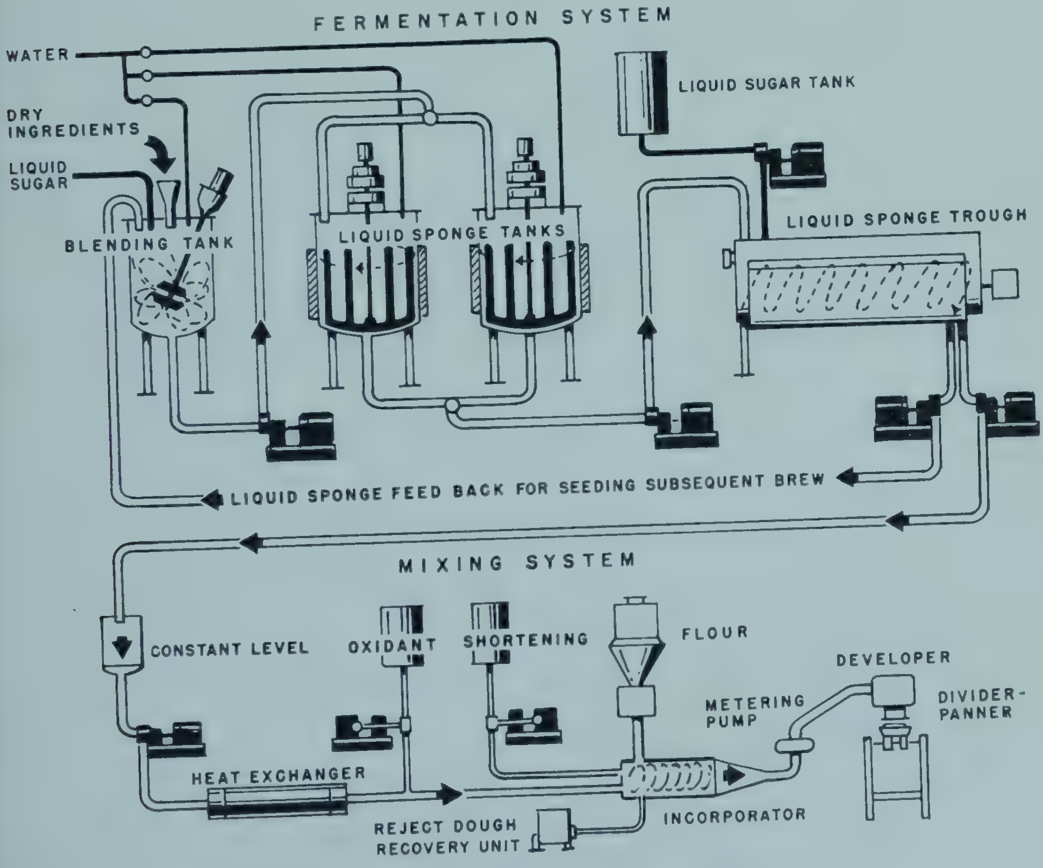
FERMENTATION SYSTEM
WATER
DRY INGREDIENTS
LIQUID SUGAR
BLENDING TANK
LIQUID SPONGE TANKS
LIQUID SUGAR TANK
LIQUID SPONGE TROUGH
LIQUID SPONGE FEED BACK FOR SEEDING SUBSEQUENT BREW
MIXING SYSTEM
CONSTANT LEVEL
OXIDANT
SHORTENING
FLOUR
DEVELOPER
METERING PUMP
DIVIDER-PANNER
HEAT EXCHANGER
REJECT DOUGH RECOVERY UNIT
INCORPORATOR

Fig. 107. Flow Sheet of the AmFlow Process

and di-glycerides, tartaric acid esters, etc. The shortening should have plastic properties satisfactory for working with warm doughs (up to 104° F.). In most cases the addition of 3 to 5 per cent hydrogenated lard or cottonseed flakes (M.P. 140° F.) helps to insure plasticity of low melting materials. At the same time the addition of flakes permits use of 95 per cent lard, and thus may indirectly add to the flavor, since the low melting fats are often more flavorful.

Milk.—Spray- or roller-dried milks are used. These should be of bakery grade quality—heat treated sufficiently so that adverse effects will not be found in dough properties. Off-odor or off-flavor milk should not be used in the production of quality bread. Milk serves as a buffer in the broth, and thus acidity is controlled. Apparently milk acts in some manner as a bio-catalyst to improve the liveliness of the yeast, and also serves to supply the yeast with some nutritive material. Good quality milk contributes a milky flavor to the finished bread if used in sufficient amount.

Salt.—Salt contributes its useful flavor effect in the ranges noted above. More than 2.25 per cent seems objectionable.

Yeast Foods.—The bromate type yeast food can be used conveniently and is used in pre-ferment processes for its ammonium salt content rather than its bromate content. The calcium salt present helps dough development properties, especially in regions where the water is naturally soft.

The bromate-iodate-phosphate type of yeast foods are also useful as a source of ammonia nitrogen for yeast stimulation, and the calcium phosphate helps strengthen dough properties and may be more useful in some districts than in others. The calcium phosphate is useful where the flours are slightly on the weak side, and mention of it in the formula above shows that it can be added by itself for improvement of dough structural purposes.

Flour.—Flours that make acceptable bread by conventional methods will usually be found to operate satisfactorily in continuous operation. It is advantageous to have an economical source of supply of flour of uniform quality and performance. Most flours being used will have from 11.2 to 13 per cent protein, will have good tolerance to mixing, and yet will not be long mixers. Good flours yield doughs of good machinability and flow properties.

Flours carrying a large amount of broken starch and making doughs of short breaking properties are difficult to process.

Some of the physical methods for testing dough characteristics seem to be useful in determination of flour quality satisfactory to continuous operation. The measurement of mixing time requirements and dough extensibility are examples. For more detail the reader is referred to a

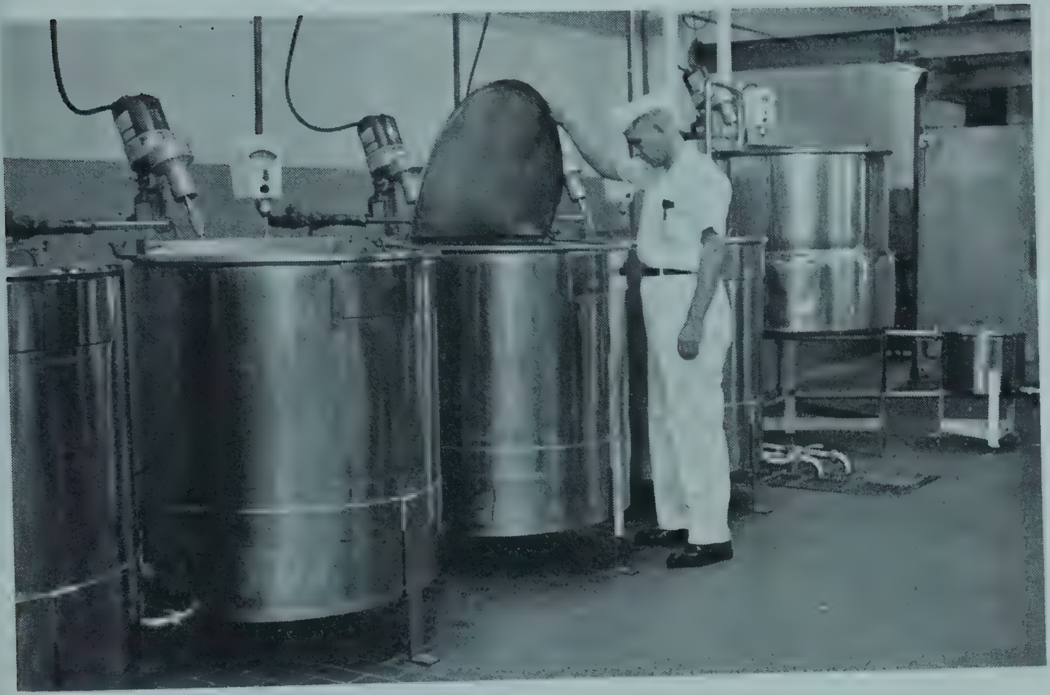

FIG. 108. DO-MAKER FERMENTATION TANKS

Stirring equipment and thermometers are shown above the tanks. On the right is a transfer tank and a constant level device.

paper read by Fortmann (1959B) at the Association of Operative Millers meeting in Chicago, 1959.

Baker's patent flour of itself has a bland mild flavor, which can carry through into the bread at times. Some authorities say that flours differ in flavor and aroma, but these effects are usually overpowered by fermentation and processing. Flour should be rated rather as a carrier of flavor than a marked contributor. Unsound flours may have an off-odor of mustiness or rancidity. In some cases flour will absorb foreign odors in storage or shipment which can go through processing into the finished bread. These last two statements are not new to the experienced conventional baker.

Mold inhibitors.—Such as sodium or calcium propionates, or sodium diacetate, are added especially in warmer regions or in the summer to lessen loss by mold. At the higher levels the propionates can contribute a characteristic odor or flavor which is rated as undesirable by some observers. More than 0.3 per cent can slow down yeast action to some extent. Diacetate at higher levels can add a sour flavor.

Oxidizing agents.—Bromate and iodate are added as a separate solution to control oxidation as required. The oxidants function as dough improvers to enhance stability and gas retention. A normal addition of

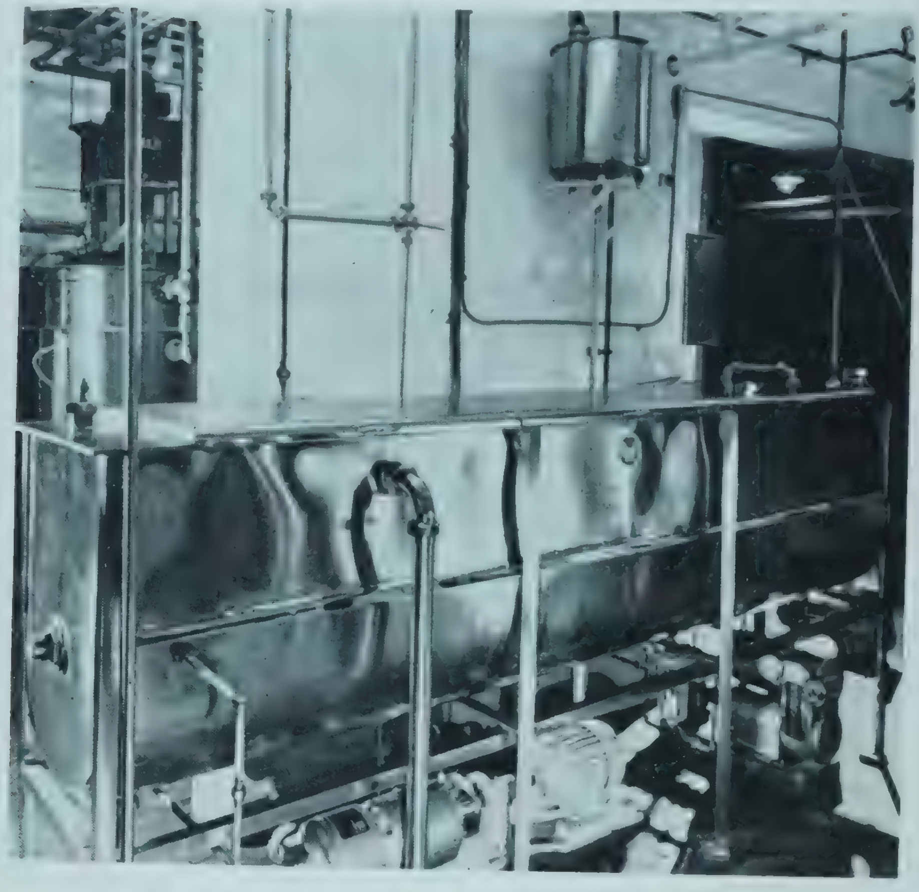

FIG. 109. AMFLOW HORIZONTAL LIQUID SPONGE TANK

In the background to the left is the holding tank.

40 p.p.m. bromate and 10 p.p.m. iodate will usually produce the desired effect. The parts per million are based upon the flour weight.

In summary, ingredients can play a role in flavor: sweetness, yeastiness, milkiness, and saltiness.

Pre-ferment Procedures

The pre-ferment of the Do-Maker process is called the "broth," that of the AmFlow process in its final state is known as "liquid sponge"—the basic ingredient difference being that the latter contains some flour. Other terms to describe the pre-ferment are "brew," "ferment," etc.

Figs. 108 and 109 illustrate the equipment used to produce both kinds of pre-ferment.

Do-Maker Procedure

The Do-Maker broth is prepared at a definite time in advance of its need for mixing with flour, shortening, and oxidizing agents in solution

The time of fermentation begins when the yeast is added to the solution of sugar, milk, salt, yeast food, vitamins, and mold inhibitor and ends when the fermenting liquor is pumped to the premixer—an average time of from 2 to $2^1/_2$ hours. The expected conversion of sugar to carbon dioxide and alcohol amounts to about $1^1/_2$ to 2 per cent during this period. At the end of two and one-half hours the yeast is fermenting at a lively rate, and its action will bring the hydrogen ion concentration down to pH 4.7, which is more or less controlled by the buffering action of the milk content of the broth. The products and effect of such fermentation have been described by Lee and Geddes (1959), Maselli (1958), Johnson and Miller (1957) and others. The Do-Maker ferment conditions the yeast for optimum dispersion of gluten, which is another way of describing mellowing of the dough due to good yeast condition. To maintain continuity each broth is "set" (yeast is added) 30 minutes after the yeast addition to the preceding broth.

The properly fermented Do-Maker pre-ferment contributes to the flavor of the finished bread. Additional sweetness can be obtained by use of enough sugar to satisfy the baker and his particular market. A long fermentation would produce a sour type of bread, but could not be used if dough properties were adversely effected. Some of the so called "sours," cultures of acid forming bacteria, could be used if conditions of time and temperature are favorable, and here again the effect would have to be controlled so that dough properties would not be adversely affected.

Some of the products of the fermentation, such as alcohol, are volatile and are mostly lost during baking. Retention of these flavorful volatiles is very desirable and in coarse textured bread retention is possible slightly longer due to less surface of the sliced loaf than in fine-textured bread.

Mention of this effect is made at this time since there is some criticism of fine-textured bread having too bland a flavor and even conventionally produced "brake and twist" bread would be in this category. While most of the continuous mixed bread presently produced is of exceptionally fine grain and texture, it is possible to open the grain of the crumb to resemble conventional bread, if there is a demand for it. Furthermore, experimentation shows that fine-textured bread can be considerably changed in flavor character and intensity. What the future holds in this respect remains to be seen. To obtain the necessary loaf volume, there is as much leavening, by means of carbon dioxide evolved in fermentation of continuously made bread, as in fermentation of conventional sponge and dough. There should also be approximately the same alcohol production and probably the same oven loss of volatile material.

The characteristics of these pre-ferments influence the resultant dough properties when mixed with flour and the other ingredients, i.e., shortening and oxidizing agents. In general too long a fermentation may weaken the doughs, whereas too short a fermentation will not sufficiently mellow the dough for best mixing and for good machining in the extrusion process which is to follow. These effects are somewhat similar to those found in conventional sponge processes, except that in the latter at dough up, the addition of fresh flour may correct for some difficulties and create slightly more tolerant conditions in the bake shop. The pre-ferment acts upon all fresh flour, so to speak, and thus continuously produced dough resembles the straight-dough process.

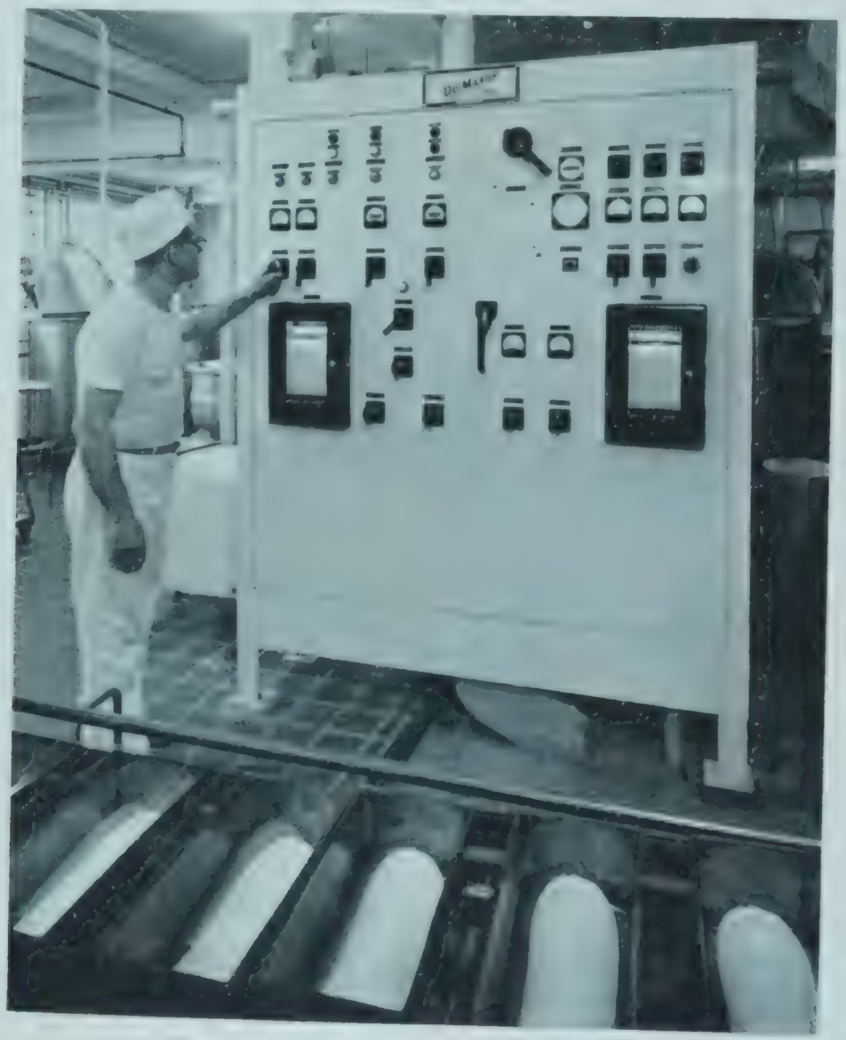

Fig. 110. Do-Maker Control Panel

Switches, indicator dials, and a recording wattmeter are visible in the background. The conveyor with panned dough is in the foreground.

Now that the ingredients, the preparation, and some of the limitations and characteristics have been described we may pass on to how this liquid constituent of the dough is conducted to the premixer which serves as an assembly point for dry and liquid ingredients (see Fig. 106).

The Do-Maker broth is pumped from the fermentation tank to the transfer tank, where it is held for some minutes to allow emptying of fermentation tank, and level out the feed rate. Then it flows through a constant level tank. A two-speed pump takes the liquid from the constant level device and forces it through a heat exchanger to the premixer.

Since there is the usual temperature rise of 10° to 12°F. in the yeast action of the ferment (corresponding to about the same amount of temperature rise in the conventional sponge) there may be times when the ferment should be cooled, so a heat exchanger is installed between the pump and the premixer. This arrangement makes it possible also to adjust for flour temperature, and thus bring dough out at the right temperature.

The flow of this liquid, as well as other liquid and the dry constituents, must be under exact control and must never stop once the machine is started. In the Do-Maker system the problem is solved by use of two-speed motors for the pumps and two-speed motors for the flour feeders. These are actuated by the load in the balanced premixer. Too much load, for example, calls for the use of the two-third-speed motor while too little returns the pump and feeder rates back to full speed.

The pump and feeder speeds are at the full speed rate 95 per cent of the time and at two-thirds-speed 5 per cent. While this is an automatic feature, the operator has the opportunity of changing each individual ingredient rate or all by increasing or decreasing speed rates from the main Do-Maker control panel (Fig. 110) where each ingredient food rate is also indicated and adjusted.

AmFlow Procedure

The AmFlow procedure for preparation of the preferment can be best described by referring to the schematic diagram Fig. 107 and the illustration of equipment, Fig. 109. Major components of the fermentation system are the blending tank, two holding tanks, and the fermentation trough each of which is equipped with special agitators.

The preparation of the liquid sponge begins with the addition of yeast, yeast food, liquid sugar and dry ingredients to water in the blending tank, into which is also recycled some of the liquid sponge. After about an hour, salt, milk and 10 to 16 per cent of the flour are added and the mix is pumped to one of the two holding tanks to develop the liquid sponge (before the addition of flour the liquid is called the "brew") which is about the consistency of high-solids milk. The remainder of the water is added at this point. A four-pronged horseshoe agitator holds the flour in suspension while fermentation continues.

From the holding tank the liquid sponge is pumped to the horizontal tank where more sugar is added according to the baker's need for sweetness, and to be sure that the yeast is sufficiently fed. The liquid sponge continues to ferment for about an hour before it is pumped to the incorporator where the assembly of oxidizing solution, shortening, and major part of the flour occurs. As previously noted, some of the liquid sponge is recycled to the blending tank in order to take advantage of some enzyme and fermentation products which may occur in flour and other ingredients to improve yeast activity and final flavor.

Other Premixer Or Incorporator Ingredients

Brief mention has already been made of shortening amounts, functions, and desirable characteristics. The shortening in the melted state is pumped to the premixer through an insulated pipe by means of a pump equipped with two-speed motors.

In preparations of melted shortening, consideration has to be given as to whether fully hydrogenated flakes (140 F. melting point) are required for best results or to correct for a shortening lacking in plastic properties. If required, the flakes can be added advantageously in the molten state to the melting shortening.

Should the baker desire a softer crumb, the permitted softeners—mono- and di-glycerides, esters of tartaric acid, etc., can also be added to the melting shortening in the blending tank. (Softeners in the water-emulsion form are not used in this procedure because of practical difficulties.) The bakery-blended melted shortening thus prepared must be held at a slightly higher temperature than 130 F. or such so that the eutectic mixture or blend is always liquid to avoid crystallization of the higher melting constituents (softeners, flakes). Solidification or crystallization cause stoppage in the insulated line or pump between melted shortening storage tank and premixer. Shortening failure can cause poor results.

The solution of oxidizing agents, potassium bromate and potassium iodate, is prepared in advance of its need and in sufficient volume to last for a definite time, such as 8, 12, or 24 hours. The amount of each reagent made up into solution depends upon the rate of bread production, or perhaps more simply upon the rate of flour flow since the bromate and iodate treatment is adjusted to the need of the flour for oxidation. If, for example, the flour needs 40 parts per million of bromate, we estimate that for an eight-hour run making 60 one-pound loaves per minute the flour flow will be 40 lbs. per minute. Thus for eight hours one can calculate that 40 × 60 × 8 or 19,200 lbs. of flour would be used, so by direct proportion (arithmetically) 0.77 lbs. (equivalent to 12.3 oz. or 349.2 gm.) of potassium bromate would be added to the oxidation solution tank containing 480 lbs. (57.83 U. S. gallons of water). The iodate required is calculated in the same manner, and, accordingly, in the above example 0.1925 lbs. would be used for 19,200 lbs. of flour if the treatment rate is ten parts per million (10 p.p.m.). Both of these oxidizing agents must be dissolved completely, and some stirring is required at the time the solution is prepared. These reagents are approved in the Bread Standards for use up to a limit of 75 p.p.m. in sum total; for example, 60 p.p.m. potassium bromate plus 15 p.p.m. potassium iodate would be a top permissible limit.

It is the function of these oxidizing agents to assist in the preparation of a dough of good physical quality so that optimum gas retention properties result during development, during proof, and in the beginning of the bake. The iodate reacts rapidly, and probably exerts its action to improve mixing development and also to increase the mixing requirement. The bromate acts more slowly and does its best work during late proof and in the fore part of the oven.

As in conventional operation, the flours made from southwestern wheats require slightly more oxidation than those made with the northern spring wheats.

If the oxidizing reagents are omitted inadvertently, unstable doughs have to be processed, and small volume, coarse grain, and coarse texture will be found in the resultant bread.

It should be pointed out further that in Do-Maker operation the one pound of oxidizing solution water per minute must be taken account of in the fixing of the proper absorption for any given flour. For absorption calculation, the presence of the oxidizing agents can be neglected as these do not essentially affect solution weight or volume. To be consistently accurate the oxidizing solution is pumped to the Do-Maker premixer by means of two-speed motored pumps.

Flour.—Flour is supplied in a controlled manner to the Do-Maker premixer by means of automatic weigh belt gravimetric feeders, which deliver the proper amount of flour per minute. A sifter is located ahead of the premixer in order to remove extraneous material such as cloth, paper, string, etc., and thus serves in the two-fold function as a means of protecting the dough mixing and pumping equipment, as well as keeping the food product free from contamination with matter which can be removed by sifting.

The gross flow of flour has to be provided by means of necessary equipment, so that there is a never failing supply coming to the automatic feeder every instant. Both pneumatic and suitable conveyor and bin systems are being used successfully. The flour can be shipped from the mill in bags, Tote bins, tank truck, or railway car. Automatic unloading and controlled storage systems in bakeries are in accord with continuous operation.

Preliminary-mixing Apparatus

The premixer of the Do-Maker process functions as an assembly point for the liquid ingredients; i.e., fermented broth, melted shortening, and solution containing the oxidizing agent as well as for the dry ingredient—the flour. Here also occurs the first wetting of the flour with liquids and consequent homogeneous admixture to form the dough. The ingredients are admitted to the head end of a two-shafted mixing conveyor, each shaft of which has a series of blades. The dough is discharged to the dough pump at the exit end. By measurement of the torque required to mix this mass of forming and moving dough, it is possible to record consistency—which some might term viscosity. At any rate, such readings are useful in observing slight changes in flow of ingredient rate, and more especially to help keep absorption levels at a steady state. The assembled dough thus prepared has no structure and little gas retaining property, for since no kneading work has been done, no development has occurred. In the Do-Maker the premixer is mounted on a pivot, and overweight and underweight of the "through-flowing" dough is corrected as described earlier. Moreover, it should be pointed out that a light on the panel indicator changes with the full to two-thirds pump rate.

In the AmFlow Incorporator the design is such that a manual adjustment must be made to maintain the dough flow to the pump ahead of the developer at constant pressure.

Dough Pump

The dough pump functions as a regulator of dough flow, and as a means of forcing dough under pressure to the developer. The control of the dough flow is necessary for exact dividing, and the regulation thereof comes from the main panel by changing the speed of the pump. Besides this control, the speed of the divider can be changed if conditions warrant, so that dough-piece weight can be adjusted. Naturally, for a major change in dough-flow rate, as called for from the panel, ingredient-flow rates must also be changed accordingly. For example, a small adjustment of 1/4 to 1/2 oz. of dough per dough piece would be taken care of with a change of dough pump speed alone, but a change from 90 lbs. of dough per minute to 100 lbs. of dough per minute would require ingredient feed rate adjustment of 11.1 per cent. The dough pump is indirectly concerned with the shaping of the developed dough piece, since the pressure of the dough incoming to the developer and outgoing from the developer is a function of the dough pump, and pressure is required to maintain "through-put" and extrusion.

The Developer

The developer is really one of the most interesting and important elements of continuous operation, for at this point the dough is changed from an assembled mass with no structure, no strength, and no property of gas retention to a smooth film-forming body (the dough at this stage can be stretched out into fine coherent and extensible films), which has superior strength and characteristics for holding the leavening gas which will be generated in the subsequent proof stage. The kneading work done in this part of the apparatus is done on a substantially de-gassed dough, and because of the 20 to 60 lbs. pressure involved and the comparatively high speed mixing action, carbon dioxide is driven into solution and into the gluten matrix as indicated by Dr. Baker's (1954) studies. Such effects can in part explain the fine grain and texture of continuously produced bread. Due to mechanical work, kneading, folding, stretching, etc., there will be a temperature rise in the finished dough of 18° to 24°F. depending upon the flour used, consistency of dough, "through-put" rate, and other conditions. Roughly, this heat rise is the same as shown in conventional batch mixers of 600 to 1200 lbs. capacity indicating that mechanical work required to develop a pound of flour is about the same in either case, but the efficiency difference is in favor of the continuous operation.

One thousand pounds of dough in conventional operation may require ten minutes to develop, and the dough, in some cases, must be cooled by ice or refrigeration during mixing. In contrast, the continuous operation can be compared on a per minute basis: 100 lbs. of dough per minute are developed in 90 seconds. In other words, the work is done on smaller dough increments in the continuous processes.

The work in the Do-Maker developer is accomplished by two vertical impellers which turn at a speed which will do the best work. Doughs of flours from different wheats or different manufacture require different impeller speeds (r.p.m.) to get the necessary work done. In general, the stronger flours of higher protein content require more r.p.m. than do the medium strength flours. A northern spring standard patent of about twelve per cent protein might require 160 r.p.m. whereas a southwestern bakers patent of 11.4 per cent protein might require 120 r.p.m. Naturally, speeds also are adjusted to take care of "through-put."

Other factors which may influence the mixing requirements of the dough may be the amounts of some of the ingredients besides flour as well as the amount of absorption; for, while the high absorption increases

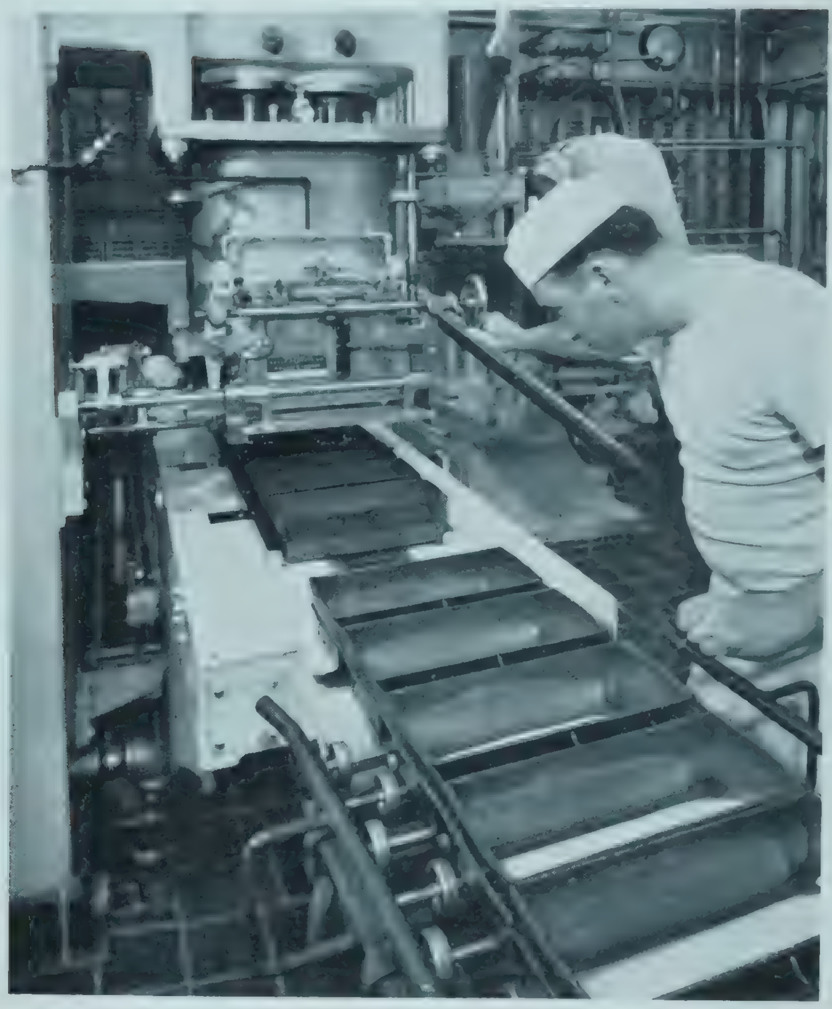

FIG. 111. DO-MAKER EXTRUSION AND PANNING EQUIPMENT

The operator is changing the control which regulates the length of the dough piece.

mixing time in conventional operation, a slight increase in r.p.m. is usual in the Do-Maker. The higher milk or shortening levels tend to call for more r.p.m., possibly to allow for more contacts between flour particles separated by dilution effect of the inert materials.

Oxidizing agents can affect mixing requirement. It has been found that best continuous operation requires roughly tenfold as much oxidation as conventional. Part of this increase in requirement may be due to lack of atmospheric oxygen in the closed system of continuous operation, and possibly part may be due to removal or change in some flour constituent due to yeast fermentation as practiced in the sponge and dough method. Oxidation seems to be necessary for good gluten development during mixing, and such action improves gas retention and stabilizes conditions. Oxidation of flours tends to lengthen mixing time in the conventional and increase r.p.m. in the continuous.

Most of the changes in mixing requirement, if these occur, will be seen on the power curve. The amount of power used in mixing the dough is continuously shown by means of a recording wattmeter, so the operator can check deviations and make adjustments on the panel in cooling water at the heat exchanger, etc. In addition to the recording wattmeter control, an experienced operator can usually pick up differences in appearance of the extruding dough piece to detect improper mixing. Under-mixed doughs show striations or laminations; over-mixing is indicated by a glossy surface and tackiness, and in start-up operations these observations are helpful in proper adjustment of r.p.m. The feel of the dough and its capacity to stretch and be drawn into films also helps the operator judge development progress and arrive at proper mixing speeds. The usual test is to run a mixing curve, to find a point of under-mixing, then over-mixing, and finally arrive at an optimum. With a flour of critical mixing performance the r.p.m. of the lower limit may be, for example, 115 r.p.m.; the upper limit 125 r.p.m. The optimum would be 120 r.p.m. A flour with good mixing tolerance would have somewhat more spread in the r.p.m. requirements; for example, a very tolerant flour with an optimum of 120 r.p.m. might have a lower limit of 110 r.p.m. and an upper limit of 130 r.p.m.

The dough is continuously developed as it progresses downward to the exit of the developer, and should be fully developed as it passes through a narrow slit opening to the extruder. After passing this point, it is shaped so that an elongated cylindrical dough piece is cut off by opposed knives as it is extruded from the divider. The knives are actuated in synchronization with the panner, and this in turn is timed to catch the falling dough piece in a properly placed pan below. The timing of the depanner and the knife stroke is adjusted so that dough pieces of the desired weight are cut off. When the operator desires to change the length of the dough piece, adjustments are quickly made to lengthen or shorten the cut-off orifice. To increase the weight of the dough piece the time of the cut-off is lengthened. Some of these adjustments call for a short period of time during which the developed dough is run through the panner into a trough below. This dough is fed back into the premixer at a low rate of addition, so no waste of material occurs nor is the time schedule seriously affected. Fig. 111 shows the dough extruding and panning operation in the Do-Maker.

Fig. 112 shows the extruder and panning equipment of the AmFlow. While the above descriptive material regarding development work has to do with the Do-Maker, there is much in common between the two sys-

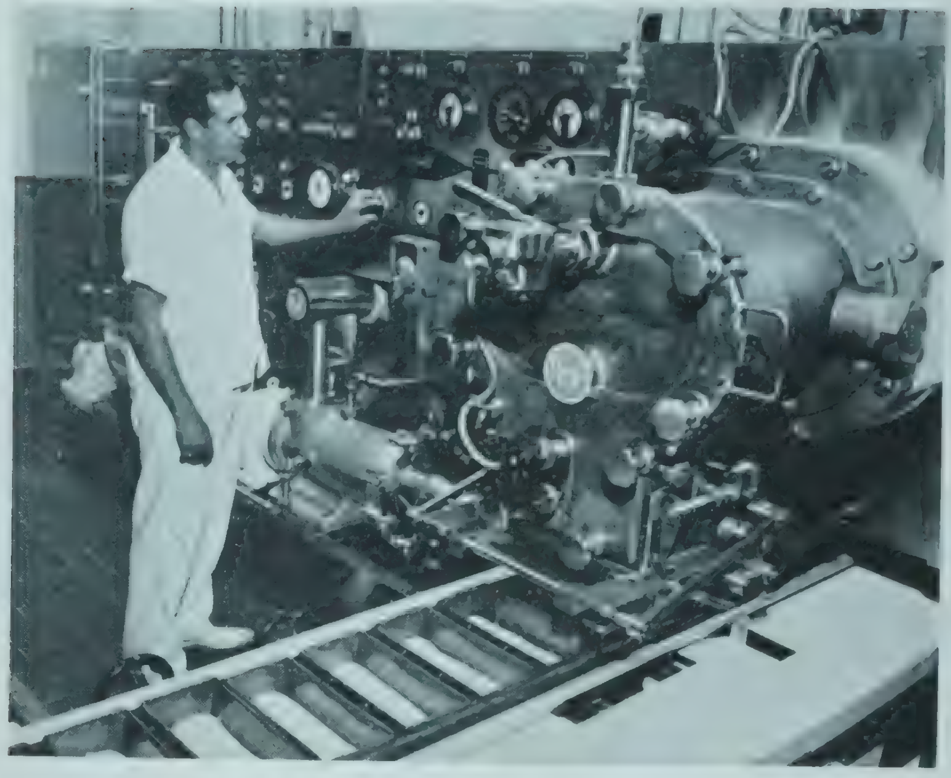

FIG. 112. AMFLOW EXTRUSION AND PANNING EQUIPMENT

Part of the control panel is also shown.

tems. However, the AmFlow impeller is driven hydraulically rather than electrically and is mounted in a horizontal position in contrast to the vertical alignment of the Do-Maker impeller. Extrusion is accomplished in a somewhat similar manner with both processes.

Once panned, the dough is conducted to the proof box or chamber, where it is allowed to ferment to height or time if a continuous proofer is used. From the proof the dough is delivered to the oven as usual. These steps are not very different from conventional operation. The exceptions will be noted and discussed, and for the first instance one finds the panned continuously produced dough is somewhat more sticky since no dusting flour is used in the processing, and it can, and usually does, carry more absorption than conventional. The proof time is approximately the same. The dough of the continuous operation will not tolerate a dry proof box, so careful attention is paid to humidity control. In general the doughs are lively and very uniform in their rise in the proof and in the oven. If lack of uniformity is noted the operator checks for cool or hot spots, which result from uneven heating or poor circulation.

The baking of the continuously made dough may require some oven adjustment when the process is first installed. As in all good operations even heat application to every loaf alike is the ultimate goal. In well-adjusted continuous operation, it is indeed an impressive sight to view the uniformity with which the baked loaves come out of the oven, hour after hour.

ADVANTAGES OF CONTINUOUS OPERATION

Having described the process and the equipment in a general way, a review of advantages of continuous operation is in order. The following list is drawn up for illustration:

(1) Continuous processing requires less floor space, since the larger air-conditioned fermentation room is replaced by smaller broth-ferment or liquid-sponge tanks. The conventional divider, overhead proofer, rounder, and dusting flour equipment are unnecessary, as are the molder, or molder-panner—all of which are replaced by more compact equipment.

(2) Continuous operation can be conducted as a more sanitary method, for the process is carried out primarily in a closed system and the machines have been designed for sanitation. The closed system lends itself well to flushing and washing procedures.

(3) Continuous operation produces a more uniform product with some new features, such as fine crumb or even soft texture and no large holes.

(4) Cost of power and ingredients is less than with conventional operation.

(5) In most cases, labor saving is an interesting item. Two men can operate either the Do-Maker or the AmFlow.

(6) Accuracy and precision of dividing means closer control and hence less tendency for the over-weight loaf. This saving can be an appreciable item in the cost of operation.

(7) The machines have flexibility of design so that they can usually be installed in an already-operating conventional bakery without serious loss of change-over time. Naturally, the building of a new bakery around continuous equipment can result in more savings and more efficient operation. The cost of installation in a new bakery should be less than conventional mixing, molding, dividing, rounding, and overhead proof equipment.

(8) Less loss of goods in preparation occurs if an oven or equipment shut-down of more than six hours duration occurs. The cost of dumping ferments is less than dumping sponges. By the same token, start up after a less-than-five-hour shut down would probably be less troublesome.

(9) The advantages in material handling, such as bulk flour handling and storage, liquid sugar, etc., lend themselves well to continuous mixing and processing.

LIMITATIONS OF CONTINUOUS MIXING

As with all new developments and changes in industrial procedures there are some limitations, which are shown below.

(1) The continuous equipment is not now economically suited to smaller bakeries. If the baker produces less than 100,000 lbs. per week, it would be a questionable change, so continuous operation at the present time is limited to large-scale operation.

(2) Raisin bread cannot be made by continuous mixing equipment on account of the mashing or breakage of the raisins. On the other hand, wheat bread and other variety bread is being made successfully continuously.

(3) The continuous processes are best suited to pan bread production. Future research and development can be expected, so that rolls can be made on a part-time basis or full-time basis.

(4) Certain steps in continuous operation are less flexible than conventional, such as allowances for "coffee breaks," loading proofer, and oven.

In Table 73, comparing the conventional with the continuous methods of bread production, the advantages of the continuous method are indicated schematically. From the operations standpoint there are fewer elements of equipment to be cleaned and maintained.

Table 73

COMPARISON OF SCHEDULING FOR CONTINUOUS AND CONVENTIONAL PROCESSING

Conventional Sponge and Dough	Continuous Processing "Do-Maker," "AmFlow"
1. Ingredients to load mixer 5-10 min.	1. Continuous flow of ingredients to premixer.
2. Batch basis mix sponge 2 to 4 min. ferment sponge 4 to 5 hrs.	2. Premixer 90 sec.
3. Remix sponge with 30 to 40 per cent fresh flour, water, salt, etc. 6 to 12 min.	3. Developer and divider 90 sec.
4. Floor time 20 to 30 min.	4. Pan
5. Divide, round, and over head proof 20 min.	5. Proof
6. Moulder	
7. Pan	
8. Proof	
Overall processing time Mixing to oven—6 to 7 hrs.	Overall processing time Mixing to oven—1 hr. 30 min.

The maintenance men in charge of continuous equipment may have to have slightly different training and background than with conventional equipment. Experience has indicated that maintenance men can be shifted from the conventional type of equipment to the other without difficulty. The cleaning phase of maintenance is simple, effective, and less time consuming. The mechanical side is not complicated, for electricians and mechanics on conventional are shifted over to the new equipment without difficulty.

The attitude of the operators of continuous equipment is entirely favorable, once they have understood and mastered the new type of machine.

CHEMICAL AND BIOCHEMICAL DIFFERENCES

Chemical and biochemical differences in the comparison of conventional and continuous methods are based mainly upon the different fermentation techniques.

In the Do-Maker system no flour is exposed to fermentation until the premixer stage, whereas conventionally 60 to 70 per cent of the flour is present during the 4 to 5 hour sponge stage and for another hour during proof. Enzymatic processes are at work during this period, so that starch is successively broken down to dextrins and sugars. That such action is not sufficient for present day conventional shop operation is demonstrated by the fact that additional sugar is added at the dough-up for both leavening action and sweetness.

In the AmFlow liquid sponge method, some flour is added to the preferment and a part of this is pumped back into the first tank (Fig. 107) in a so-called "seeding" step, hence enzymes have more time to act on this portion of the flour. In this respect the AmFlow liquid sponge procedure lies between the Do-Maker broth and the conventional sponge and dough method.

In the AmFlow process there exists the possibility of early and late, or young and old fermentation product blending which is said to be useful in fermentation flavor control. The Do-Maker operator can also perform this step to a point, should he add flour to the broth and then blend young and old broths at the holding tank. The Do-Maker, however, is definitely limited to not more than ten per cent addition of small amounts of flour to the broth on account of pumping and metering problems that would occur due to flour-sedimentation, foaming and sludge formation.

How much starch in the flour is converted by these dilute processes has not yet been reported. Definitely, continuous processes with preferments as the main liquid ingredient must use sugars other than those derived from flour for their main fermentation to produce the necessary leavening power. The nature and production of flavorful fermentation products from the flour in the pre-ferment will undoubtedly be reported upon more extensively.

Proteolytic enzymes present in flour can have an effect in mellowing the gluten in the time period of the sponge and dough process, but show small effects in the hour of proof and the first few minutes of the oven stage in continuous mixing. Additional enzymes of this nature, such as are found in malt of wheat and barley or produced by the action of fungi and bacteria on wheat bran, can be useful in conventional operation but have minimal effects in continuous operation.

Lipase, naturally present in flour, seems to play little role in either process unless the flour fat has been split or partially split to produce fatty acids before it is added to either process.

Lipoxidase, also naturally present in flour, can have a demonstrable effect in conventional mixing, but little effect in continuous mixing. Since atmospheric oxygen is beaten into the dough in conventional operation, some bleaching can occur and some oxidation of flour fat or shortening can result. If conditions are favorable these oxidized fats could approach rancidity in flavor and aroma. Added lipoxidase in the form of defatted soy bean flour can help control and enhance this effect. When properly applied many observers classify the aroma and flavor as desirable.

The closed systems of continuous processes virtually exclude atmospheric oxygen, so lipoxidase action is practically nil. In part, this may account for difference in aroma and flavor which some observers report between bread of the two methods. The usual comment is that continuous-process bread is more bland than conventional.

Fortmann (1958B) has pointed out that determination of carbonyl content of fats in bread confirms some of the arguments regarding lipoxidase action in bread-making and suggests addition of some of these flavorful ingredients to both conventional and continuous processing. Careful control would be required for acceptable results.

The whole subject of flavor in bread has had considerable study and most of the published work has been reviewed by Otterbacher (1959). A prediction can be made that research along the lines of aroma and flavor improvement will bring forth favorable results in due course. Certainly the work of Wiseblatt at the American Institute of Baking and others confirms this statement.

Before leaving this part of the subject it should be pointed out that there are some bread flavor experts who maintain that the bland property of bread is the real reason for its popularity as a staple food. These authorities cite the experience that bread is rarely eaten alone; butter, cheese, ham, hamburger steak, etc., are the flavorful wanted components and bread is the carrier.

It is a curious fact that only about three per cent of the bread sold is made with whole wheat meal, either in combination with flour or alone, so actually the taste of bran may not be the "wheaty" aroma or flavor which is most desired and the real flavor resides in the fat of the flour, just as it does in the fat of most meats and some other foods.

To conclude this discussion on flavor and aroma of continuous and conventional bread, it is appropriate to comment that if sufficient problem differences are found, there will undoubtedly be some means discovered to resolve them. The practical evidence of swift acceptance is that an estimated 40,000,000 lbs. of continuously-made bread were marketed in 1959.

OTHER CONTINUOUS MIXING PROCESSES

In continental Europe other continuous mixing and processes seem to be making progress in large scale production. The Russians have continuous operation on a tonnage basis for production of rye bread and other goods. In Sweden, the Iverson process is used mainly for production of their specialties, with some white pan bread reportedly being made. The Strahmann process in Germany does not seem to have been worked on more than an experimental scale. According to the literature, it would appear that these processes are mainly adapted for the baked goods of their particular region, such as the hearth bread types, and for making bread of a coarser and denser grain and texture than would be acceptable in the United States or Canadian markets. The design of the kneading or developing apparatus would lend itself to the production of that type of bread.

There is no doubt that the advantages of continuous mixing processes are appreciated abroad, and that improvements will be made to meet their own problems. An interesting difference is shown by the plan of European operation whereby the dough ingredients are continuously mixed and then allowed to go through bulk fermentation (to first punch of straight dough) sometimes on moving belts, before processing with machines such as dividers, rounders, molders, etc. This procedure would mean processing a dough with considerable leavening gas present and thus would not contribute to fine grain and texture, or perhaps to best dividing conditions. The experimental work of Prof. N. F. Gatilin and I. L. Rabinowitsch and others in Russia, as reported by Goroschenko (1957), will be watched with much interest.

THE FUTURE FOR CONTINUOUS BREAD MAKING PROCESSES

In closing the chapter concerning continuous bread making processes, the author ventures the prediction that the acceptance of continuous processes will continue at an accelerated pace which will be more rapid than the conversion to mechanization and automatic operation has been proceeding in conventional batch-type methods. What will happen in smaller bake shops is an interesting question. Perhaps the individuality of their own craftsmanship will be enough to preserve them from the uniformity and excellent quality of the big manufacturer and keep an interesting share of the business for them. At any rate continuous operation is here to stay and be improved upon. It is better suited to keep up with the problem of feeding the increasing population and keep step with automation and economic efficiency.

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CHAPTER 18

John A. Dersch

Bakery Ovens

IMPORTANCE OF THE BAKERY OVEN

What criteria can be used to select the key machine in a modern bakery? Through the years, the various answers proposed have followed totally unrelated concepts. Some have felt that the initial cost of a piece of equipment automatically justified placing it at the top of the list. Others thought that the machine requiring the most care and maintenance deserved first consideration.

Whether or not the question was ever resolved will not be determined here, but it is readily apparent that barring initial cost, several machines run close competition with regard to mechanical complexity, the demand for maintenance or adjustment and the need for comprehension of basic and inherent functioning.

Perhaps the oven justly deserves this position as "key machine" in the bakery because it is without a doubt the focal point of production. All other machinery is geared to supply the oven requirement.

It is not within the scope of this book to go into a detailed history of the baking oven, but a brief description of the various types of ovens and how they evolved is necessary.

TYPES OF BAKERY OVENS

Peel

Although the peel oven, Fig. 113, has been used for centuries, there are still some in use in bakeries today which have deviated very little in design from those used by the ancients. The peel oven originally had one opening in the front. The fuel, usually wood, coke, coal, peat or lignite, was fed through this opening, ignited and allowed to burn for hours. During this heating period, the front opening also served as the only stack. After the oven had reached the proper temperature, determined only by the eye and judgment of the master baker, the embers were raked out, and the oven was allowed to "lie down" for an hour or so to secure an even distribution of heat. At the end of this soaking period, the loaves were individually loaded into the oven by means of a long-handled wooden shovel called a "peel." This naturally meant that those loaves which were

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loaded first were the last to be unloaded. It can readily be seen that uniform loaf color, consistently the same on all loaves, was the exception rather than the rule. In fact, the baker had to be a master to produce fine products from an oven of this sort.

The only good attribute of this oven was its excellent steaming characteristics. It was common practice, after the fire was pulled, to start the baking schedule with the product requiring the highest temperature. This normally resulted in the rye breads being held until the last part of the bake. At this time, the hearth was saturated with water which produced a most effective steam pocket in the high dome or crown of the peel oven. The rye bread was thus baked at a relatively low temperature in a perfect envelope of steam. This fundamental principle of steaming was overlooked for years during the evolution of the double lap oven, which will be discussed later.

The basic fault of the peel oven, "first in and last out," led to the draw plate oven and the rotary oven.

Draw Plate and Rotary

These ovens are illustrated in Figs. 114 and 115. They are grouped together because both were intended to overcome the basic fault of the peel oven. The oven proper was still essentially the peel oven augmented by an external heat source. The main difference was in the loading. The draw plate oven was provided with a sliding plate or tray hearth which could be withdrawn from the oven for loading and unloading.

In Europe the plate, which was made of iron at first, was later changed to an iron framework with an inlaid tile hearth. It was mounted on rollers running on tracks. In the United States the hearth was made of one-fourth inch thick solid steel plates. It was common practice here to use a double-deck construction with a single furnace for the two decks. British design utilized separate fire boxes for each deck. Sometimes they were built in batteries with a common heating system and 3 or 4 adjacent draw plates.

The bake obtained was more uniform than that from the peel oven, but loading and unloading was an extremely hot and uncomfortable job. The oven gained little popularity in the United States, although it was favorably received in England and Germany where some are still in use.

The rotary oven overcame the objection to hot loading and unloading by utilizing a flat, horizontal circular hearth which was constantly rotated by a drive motor and gear reducer. The product was peeled onto the hearth as it rotated past the oven door. After the circular hearth was fully loaded, the door was closed, and the hearth continued to rotate until the bake was complete. This rotary motion during the bake tended to reduce the effect of any local hot spots in the oven. At the end of the bake, the

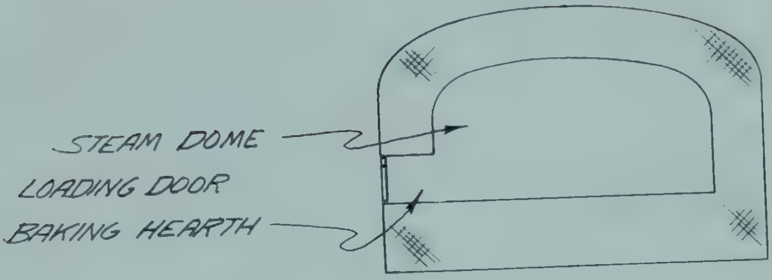

STEAM DOME
LOADING DOOR
BAKING HEARTH

FIG. 113. PEEL OVEN

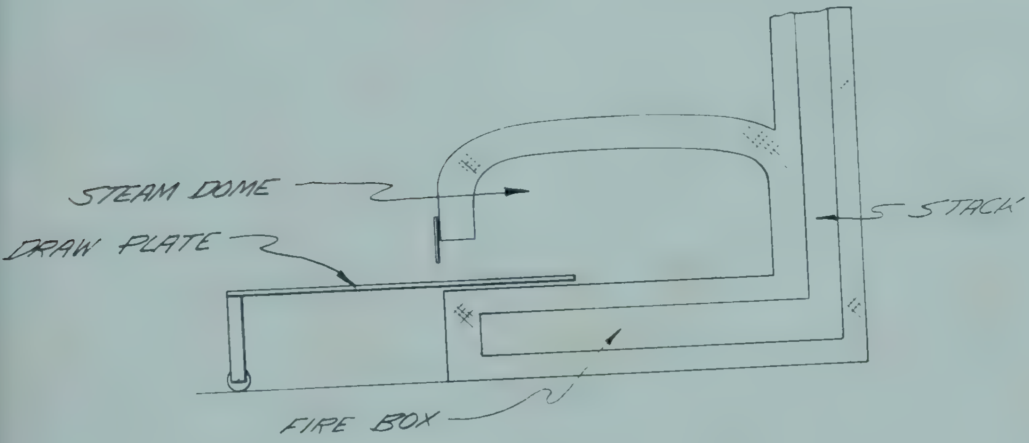

STEAM DOME
DRAW PLATE
STACK
FIRE BOX

FIG. 114. DRAW-PLATE OVEN

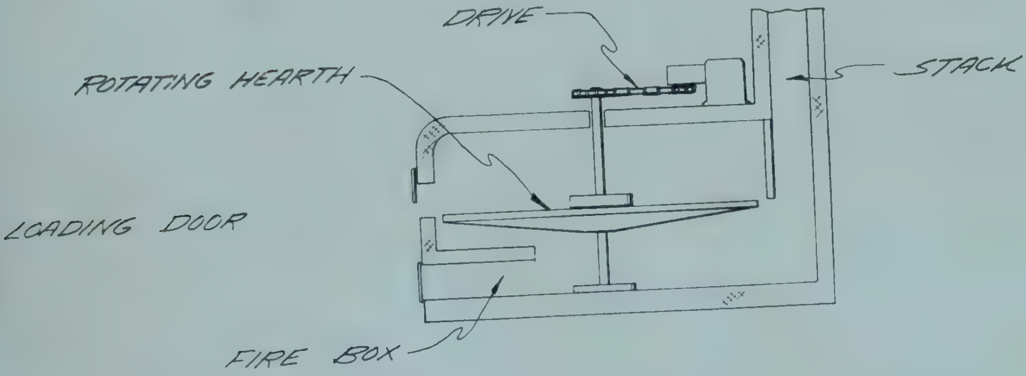

DRIVE
ROTATING HEARTH
STACK
LOADING DOOR
FIRE BOX

FIG. 115. ROTARY-HEARTH OVEN

operator could remove first the product which has been loaded first, thus obtaining a reasonably uniform bake on all of the pieces in the oven.

Reel Ovens

The reel oven (see Fig. 116) was the first of what might be termed the modern mechanical tray ovens. The baking hearth was composed of four or more trays or shelves suspended between two reels (wheels), hence the name. The machine resembled a ferris wheel, the trays maintaining

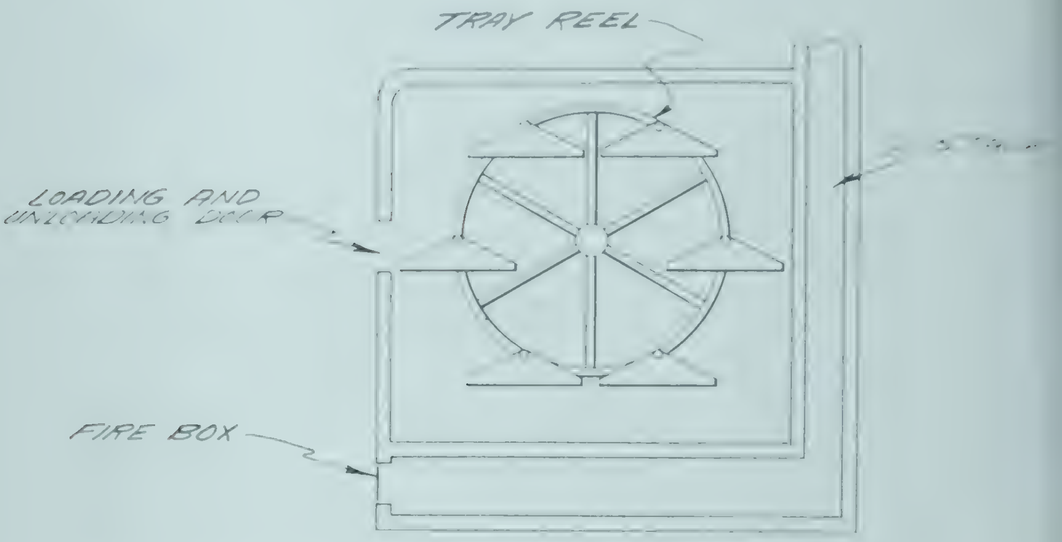


Fig. 116. Reel Oven

their level position by virtue of a high pivot point and low center of gravity similar to the ferris wheel.

As the popularity of the reel oven increased, various types of tray stabilization came into being which overcame the obvious objections to the free-swinging tray. The oven was operated in the same manner as the rotary oven except that the operator could conveniently reach all portions of the tray, and peels were unnecessary except for hearth bread or rolls. The basic objection to the reel oven was the raising and lowering of the product from the bottom to the top of the oven. With the heating system located at the bottom of the oven, it was difficult to obtain uniform baking chamber temperatures throughout. The oven occupied very little space and won a permanent spot in the baking industry's small retail bakeries.

Multi-Cycle Tray Oven

Although the reel oven and the mechanical tray oven both employ trays, the industry differentiates between them. When the two "reels" are increased to four with a chain connected between each pair, and trays are suspended between the chains, the arrangement is called a "tray" oven. The expression "traveling tray oven" is sometimes used, but the word "traveler" was first used in conjunction with the tunnel oven.

In the early 1930's, the small multi-cycle tray ovens were developed to augment the line of mechanical tray ovens. These ovens, usually less than fifteen trays, are run continuously and intermittently. In order to load rapidly, the trays are automatically stopped, loaded and indexed. The loading door is then closed, and the oven allowed to run, making perhaps 5 or 10 laps before the pre-set baking time has run out. Because baking time is pre-set, the loader does not have to wait around idly for a tray to come into position. The term "multi-cycle" is often used for this type of operation. When the number of trays becomes great enough (over 15 trays) so that the pause for loading is not excessive, a single cycle is used for the entire bake. Tray ovens employing the single cycle principle of operation can be further subdivided into two types; the single-lap and the double-lap tray ovens. These two ovens assume separate identities because of the path which the trays follow when passing through the oven.

Single Lap Ovens

This oven was designed around 1928 primarily to save space. The first single-lap ovens were somewhat of a compromise in baking performance. The reason for this was the inherently long flow time required for unloading proofer racks. This produced non-uniform products, and it was not until automatic loading and unloading and faster baking times came about that the problem was solved. A typical single-lap oven is shown in Fig. 117.

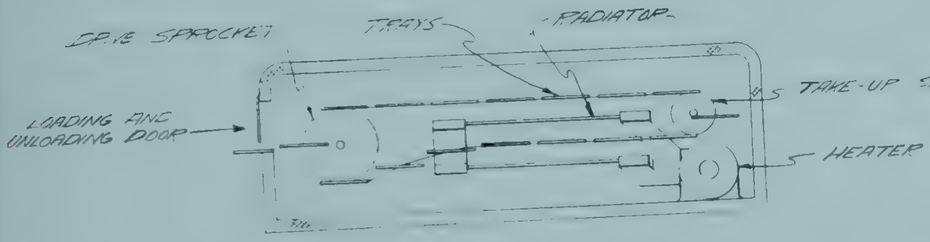


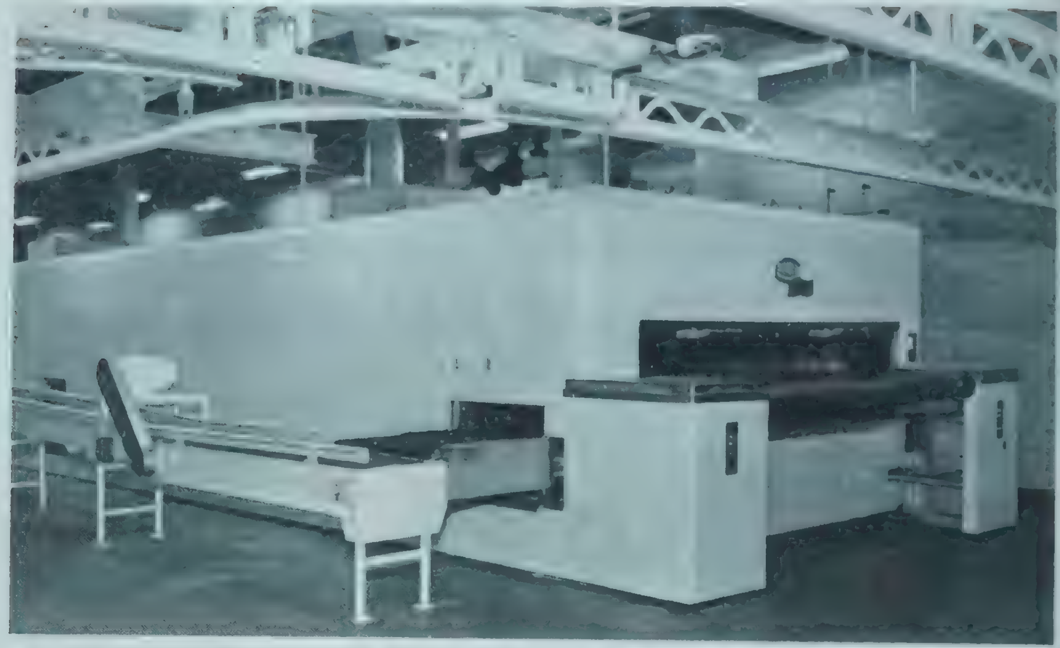
Fig. 117. Single-Lap Tray Oven

Today, products equal in quality to those obtained from a tunnel oven are produced in well designed tray ovens. In addition to a reduction of the required floor space, the modern tray oven features loading and unloading at the same end, which often simplifies the bakery layout. Single-lap tray ovens can be built to produce more than 10,000 pounds of bread per hour, which at one time was considered quite a feat even for a tunnel oven.

Double Lap Ovens

Up to about 1924 the only truly mechanical traveling oven was the tunnel oven, which occupied a large floor area. At this time, the double-lap oven was designed to be produced more economically and occupy less floor area.

The double-lap tray oven, as the name suggests, is a single-lap oven folded back on itself. The single-lap oven has two horizontal runs while the double-lap has four horizontal runs. The single-lap has two turning



Courtesy of Read Standard Div.

FIG. 118. MODERN LARGE CAPACITY SINGLE-LAP OVEN

points or two pairs of sprockets like any ordinary conveyor. The double-lap has five turning points or five pairs of sprockets, two of which are used to carry a vertical or inclined run of trays. In some designs, some of these sprockets are replaced with curved track or shoes. Fig. 119 is a diagram of such an oven.

The double lap oven occupies even less space than the single lap. It is not economical to build double lap ovens with fewer than 30 trays because of the complexity of the drive and heating requirements. In the past few years, the double lap oven has found an extremely important place in large production bakeries where floor space is at a premium. Again, increased technology and experience has led to the improvement of the double lap oven to the extent that bakes equal to the tunnel oven can be expected. Double lap ovens are in operation today, capable of producing over 10,000 pounds of bread per hour. A modern oven of this type is shown in Fig. 120.

Tunnel Oven

Although the rotary and reel ovens were mechanical to the extent that the hearths moved for easy loading, the tunnel oven was the real bridge between the batch type of bread production that existed before the turn of the century and the fabulous automatic bread plants that are a reality today.

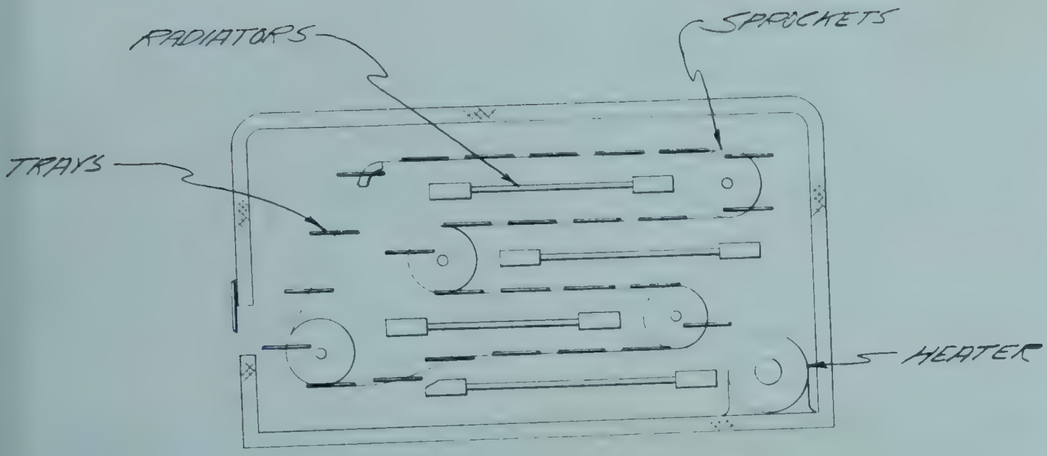
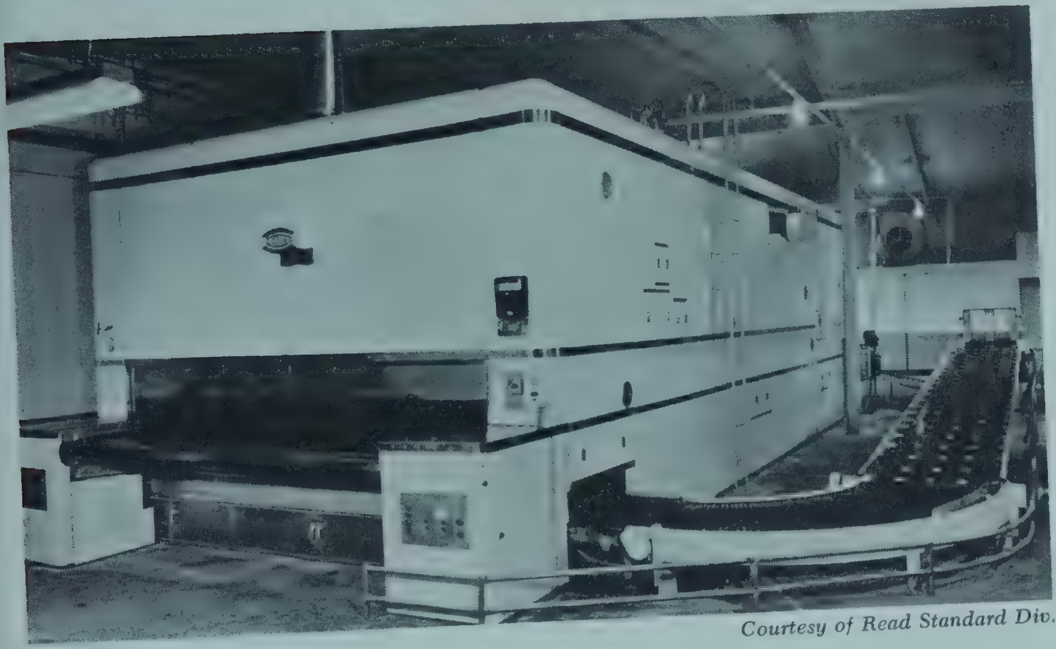


FIG. 119. DOUBLE-LAP TRAY OVEN



Courtesy of Read Standard Div.

FIG. 120. MODERN LARGE CAPACITY DOUBLE-TRAY OVEN

In 1904 the first coal-fired tunnel oven was built in North America. It was not until 1913 that the first tunnel oven was constructed in the United States, and after more flexible heating systems were designed, it became the "work horse" of the industry.

Even after the space-saving tray ovens were accepted, the tunnel oven still held the predominant position where large capacity ovens were required. Loading at one end and unloading at the other end offered many layout advantages when production requirements were large (see Fig. 121).

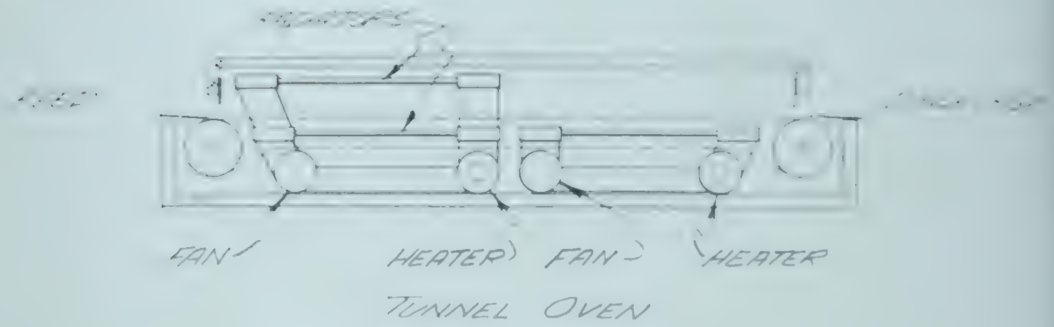
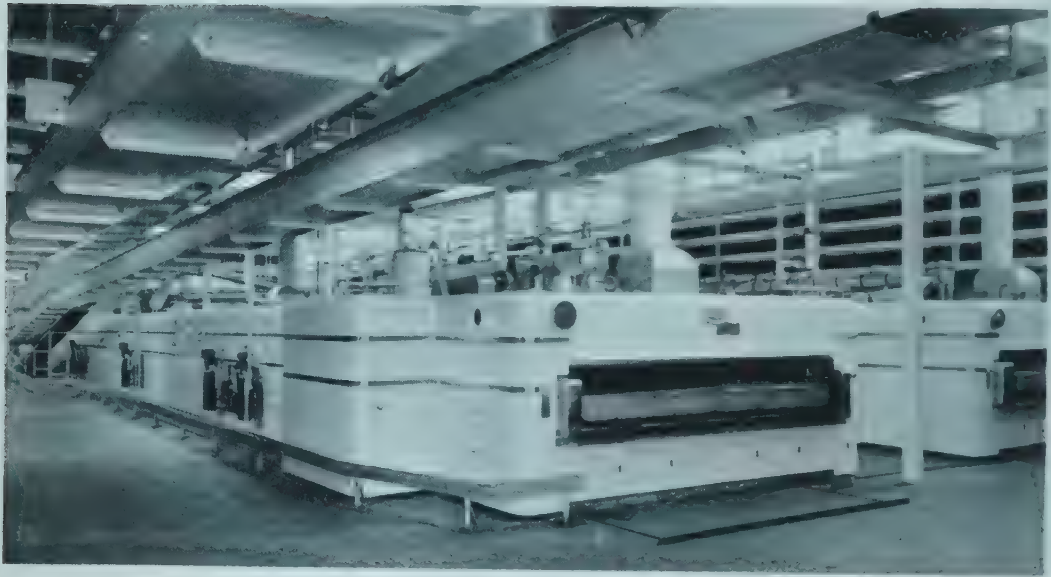


FIG. 121. TUNNEL OVEN



Courtesy of Read Standard Div.

FIG. 122. MODERN TUNNEL OVEN

The high accuracy and consistency in temperature control in the various heating zones of the tunnel oven offered great uniformity in bake and flexibility in top and bottom heat control. The long, continuous hearth had unlimited flexibility with respect to pan sizes. The mechanisms were simple and long lasting. It was only the high initial cost and excessive floor space requirements of the tunnel ovens that hastened the needed improvements in the tray ovens. A modern tunnel oven is shown in Fig. 122.

THE BAKING PROCESS

In order to build a bakery oven capable of satisfying the fundamental requirements, one must first understand what the oven is supposed to do. In engineering terms—"the problem must be clearly stated!"

Basically, the modern baking oven is nothing more than a mechanical conveyor surrounded by an insulated box equipped to supply sufficient heat to satisfactorily bake the product. The mechanical requirements are not difficult to satisfy. It is simply a question of selecting the proper chain and sprockets, the proper method of drive and tray stabilization and the proper structural framing members. The design of the heating system can be approached much more intelligently if the baking process is understood.

The reactions that take place in the oven can be divided into two classes; the physical changes and the chemical changes. These reactions must take place in the proper order, at the specified temperature, in the correct time and in the proper atmosphere. They are as follows:

Physical	**Chemical**
Film formation	Yeast action
Gas expansion	Carbon dioxide formation
Gas solubility reduction	Starch gelatinization
Alcohol evaporation	Gluten coagulation
	Sugar caramelization
	Browning reaction

Fig. 123 shows graphically the temperature at which these reactions take place.

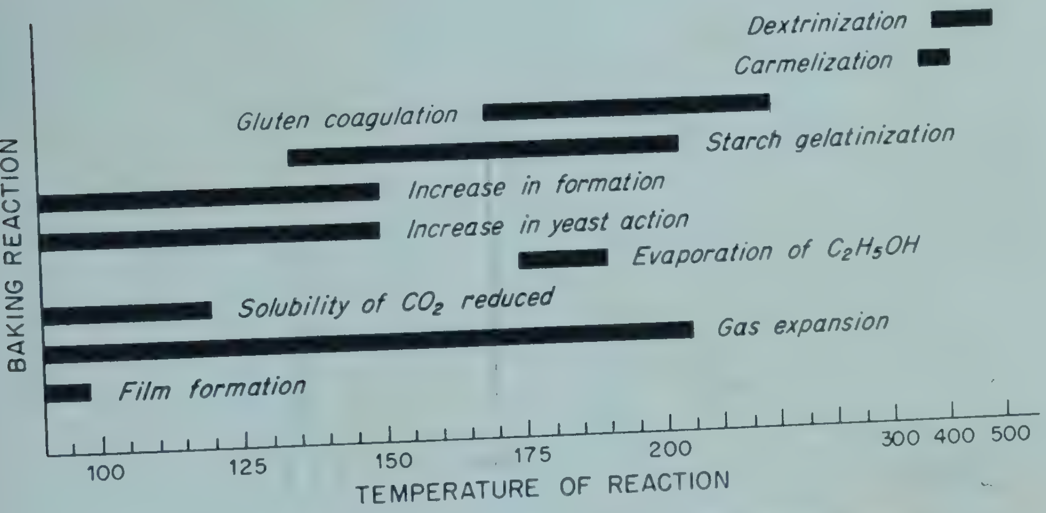


FIG. 123. THE DOUGH REACTIONS TAKING PLACE DURING BAKING

Although the presence of a film encasing the dough piece can be noticed during the steam proofing process, this film becomes much more apparent when the dough piece is first placed in the oven. The comparatively hot (425° to 500°F.) oven atmosphere causes the film to thicken and become more elastic. The elasticity is a direct function of the moisture content of the oven atmosphere.

Another physical phenomenon that begins as soon as the dough is placed in the oven is the reduction in the solubility of the entrapped gases. This is an important factor contributing to the product's oven spring. The gas most active in this reaction is carbon dioxide. In addition to being present in the dough as a free gas encased by the gluten structure much of the carbon dioxide is dissolved in the dough liquid or bound by weak forces to other dough constituents. As the internal loaf temperature rises to around 120° F., the dissolved and bound carbon dioxide is released.

The hot oven atmosphere also immediately causes the gases contained within this elastic film and held by the gluten structure to expand. Actually, it is a practical example of the Charles Gas Law, which as generally stated is: The volume of a definite quantity of gas at constant pressure is directly proportional to the absolute temperature, or that

$$V = kT$$

Last of the physical changes is the evaporation of liquids. The most important of these liquids are water and alcohol. The water enters the process as a liquid and leaves as liquid and water vapor. The ethyl alcohol is produced during the fermentation process by the action of the yeast on some of the sugars in the dough. When the internal dough temperature reaches 176° F., the alcohol begins to evaporate, increasing the internal vapor pressure and further contributing to the oven spring.

The yeast action is a continuing one that begins in the fermentation room. It ends in the oven when the internal loaf temperature reaches around 145° F. The principal products of yeast action are carbon dioxide and ethyl alcohol.

The production of the carbon dioxide is accelerated as the loaf temperature increases to the 145° F. point. This also must be considered as another factor contributing to oven spring.

When starch and cold water are mixed, the starch will absorb about 30 per cent of its weight in water. Although the granules swell slightly, the water can be removed and the starch dried to its original state without any permanent change. As the mixture is heated to 130° F., an irreversible change takes place. The starch granules begin to absorb water very rapidly and swell until they become several times their original size. This reaction is known as gelatinization.

The proteins making up the gluten of the dough are subject to an irreversible denaturation when they are brought to high temperatures. This denaturation is characterized by decreased solubility and extensibility of the protein fibers. As a result, the vesicle walls become more or less fixed, and expansion virtually ceases. This reaction begins at 165° F.

When such sugars as fructose, maltose and dextrose are heated to around 340°F., the molecules combine to form colored substances called caramels. 170°C This reaction, known as caramelization, can only take place in the crust because the internal loaf (crumb) temperature never exceeds 212°F.

The browning reaction starts at around 320°F. It is the result of heating reducing sugars with proteins or other nitrogen-containing substances to form compounds called melanoidins. Melanoidins look like caramels, and at the lower temperature taste similar to caramels. When temperatures of 475° and 500°F. are reached, the melanoidins become black, bitter and insoluble. This is the reaction that causes the disagreeable flavor in scorched or burnt bread.

Steaming

Although the steaming reaction in a bread oven can be considered as one of the many phases of the baking process, it is important enough to be considered separately.

Steam is essential in the bakery oven for three primary reasons: (1) production of a glossy crust, (2) prevention of split crusts, and (3) agitation of oven atmosphere.

The use of steam to create an agitated oven atmosphere is rapidly becoming a thing of the past. It has been found that oven atmosphere can be either partially or totally agitated much more economically and efficiently by use of large volume (2000 to 8000 cu. ft. min.) recirculating fans.

Successful steaming conditions in an oven depend on the physical characteristics of the steam and the manner in which it is applied. Various terms are used by the baker to describe the type of steam he desires. He speaks of "wet," "soft," "dry," "hard" and other types of steam. Actually, he is referring to a varied combination of the physical characteristics of the steam and its velocity. For example, "hard" steam is a superheated, high velocity steam. The engineer is interested in a more specific description, enabling him to reproduce the effect. "Saturated," "saturated with mechanically entrained water vapor" and "superheated or degrees of superheat" are terms that clearly define the condition of the steam.

Velocities in terms of feet per minute or miles per hour from the steam injector orifices must be known in order to reproduce desired effects. It should be clearly understood, however, that these terms only allow the engineer to reproduce effects. The results of steam application must be evaluated visually by an experienced baker.

After many years of trial and error in the bakery and limited laboratory work, it is generally agreed that low pressure (2 to 5 p.s.i.g.) saturated steam with orifice velocities at the injectors of 200 to 500 feet per minute provide the best steaming results. The reasons why low pressure steam is more satisfactory are fairly obvious. In order to produce crust gloss and prevent crust splitting, the steam must condense on the loaf. The higher the pressure of the steam, the more degrees of superheat carried along into the oven. Fifteen p.s.i.g. steam is at a temperature of 250 F. and carries 38° of superheat. One hundred p.s.i.g. steam is at a temperature of 338° F. and carries 126° F. of superheat. In order to condense this high temperature steam, the superheat must be absorbed. The loaf as fed into the oven at a temperature of 90° F. can condense more water vapor at a faster rate from steam at 220° F. than from steam at 300° F.

One can reason from the above explanation that time is also of great importance. The loaf must cool and condense the steam before the crust temperature itself reaches 212° F. Actually, tests have indicated that the steaming reaction is essentially complete in 1 to 2 minutes. Therefore, it becomes easier to understand why the velocity of the steam from the injector orifices is equally important. The faster the steam is carried around the loaf, the less time is available to condense a given volume of steam. Heat transfer from the steam to the loaf is increased because the film coefficient is reduced and the loaf temperature rises abnormally fast, making condensation even more difficult. All of this results in poor and inefficient steaming.

The importance of correct steam application can best be summed up by comparing the amount of steam that must be introduced to the oven artificially to that produced naturally. Steam in an oven comes from the following sources:

(1) Vaporization from dough—2.7 cu. ft./lb. dough (at 212° F.)
(2) Product of combustion —0.9 cu. ft./lb. dough
(3) Injectors —9.25 cu. ft./lb. dough

Heat Transfer in the Bakery Oven

In order to give the reader a better understanding as to what a bakery oven must do and how it can accomplish this, some of the basic concepts of oven design must be known. A review of some fundamentals of heat transfer, air flow and mechanics is the logical background for a thorough understanding of bakery ovens.

A definition of terms is essential. First, the baker's terms:

Flash heat—A heat condition in an empty oven, resulting in an overabundance of heat to the first product introduced; gives the effect of a higher oven temperature than actually indicated by the temperature-sensing element.

Solid heat—A heat condition in a partially loaded or continuously filled oven that produces a steady, even flow of heat to the product.

Flash pan—A bread pan or other metal container partially filled with water, rock salt, asbestos or sand, used for the first several rows or trays when a run is begun to absorb the "flash heat."

Lateral heat—The even or uneven distribution of heat across (when facing oven end) the oven from the radiating tubes, direct gas fired ribbon burners or jet slots.

Top heat—Heat radiating or forced downward on top of the product; not to be confused with the radiating tubes or ribbon burners in the *top* section of a single or double lap oven.

Bottom heat—Heat radiating or forced upward to the bottom of the product.

Zone—That portion of the heating system capable of being independently controlled, either by a temperature controller or damper.

Handing—The handing or operating side of a tray oven is designated as right or left when facing the *front* of the oven; the handing or operating side of a tunnel oven is designated as right or left when facing the *feed* end of the oven.

The engineering terms commonly used are:

B.t.u.—British thermal unit or the heat required to raise the temperature of one pound of water through one degree Fahrenheit.

Heat transfer—The moving of heat from one or more heat sources to a material whereby the temperature of the material is either raised or lowered.

Specific heat—The number of B.t.u. required by one pound of a substance to raise its temperature one degree Fahrenheit.

Thermal conductivity—Measure of the ability of various substances to transfer heat from one surface to another expressed in B.t.u. per hour per square foot of surface area per degree Fahrenheit per foot of thickness.

Free convection—The natural transfer of heat between a fluid and a solid at velocities resulting only from density differences in the fluid.

Forced convection—The increase in velocity of natural convection by use of fans or blowers to impart acceleration to the fluid.

Conduction—The transfer of heat in a solid caused by the vibrating molecules at a high energy level transmitting some of their energy to adjacent molecules at a lower energy level.

Radiation—The transfer of heat energy through space to some opaque object.

Heat of vaporization—The heat required to change a liquid at its boiling temperature to a gas at the same temperature.

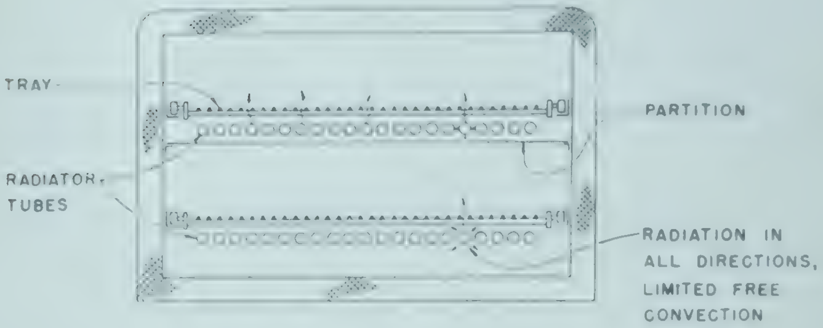


Fig. 124. Indirect Radiation Heating System for a Tray Oven

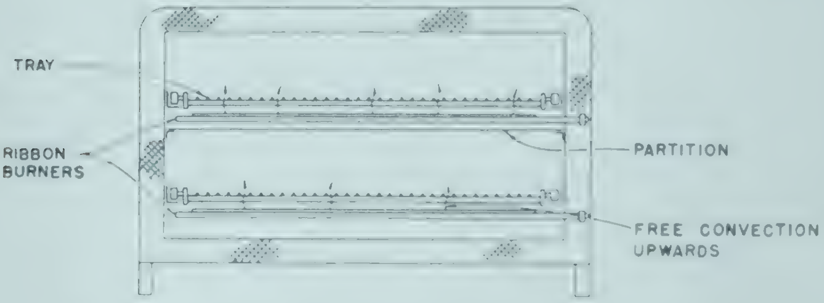


Fig. 125. Direct Natural Convection Heating System with Ribbon Burners

Heat of condensation—The heat given off when a gas at its condensing temperature changes to liquid at the same temperature.

The primary forms of heat transfer with which the oven designer is concerned are radiation, conduction and convection. At one time it was felt that radiation was the most important form of heat transfer in a bakery oven. This idea has gradually given way to the most effective and practiced approach today, which utilizes the many advantages of forced convection.

The efficiency of heat transmission by radiation varies with the temperature of both the radiator and the absorbing medium which, in this case, is the product being baked. The actual quantity of heat transferred is proportional to the difference of the fourth powers of the absolute temperatures and to the square of the distance between the two media. Other factors such as shape, color and surface affect the radiator and absorber and must be considered.

Conduction plays a relatively small part in the baking of bread but cannot be ignored. The type of hearth, pan and product must be analyzed when considering conduction. Once a design is established and a specific type of hearth and pan are decided upon, little can be done to increase or decrease the heat transfer by conduction. It has the minimum of vari-

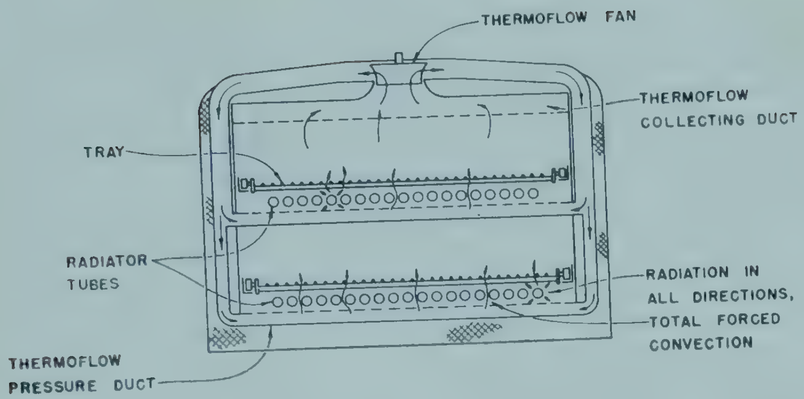

THERMOFLOW FAN
THERMOFLOW COLLECTING DUCT
TRAY
RADIATOR TUBES
RADIATION IN ALL DIRECTIONS, TOTAL FORCED CONVECTION
THERMOFLOW PRESSURE DUCT

FIG. 126. AN OVEN HEATED BY INDIRECT RADIATION AND FORCED CONVECTION

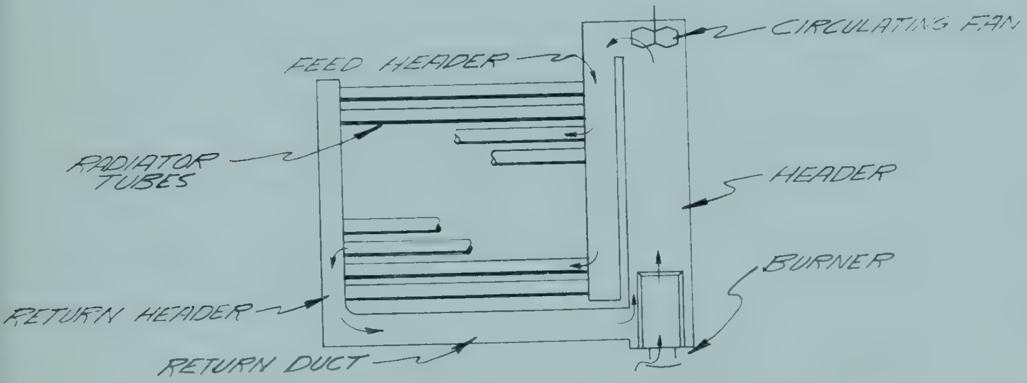

CIRCULATING FAN
FEED HEADER
RADIATOR TUBES
HEADER
BURNER
RETURN HEADER
RETURN DUCT

FIG. 127. PLAN VIEW OF RADIATOR AND HEATER SYSTEM

ables, and therefore, can be accounted for and calculated with a high degree of accuracy.

Convection is the one form of heat transfer that has been the least understood and the most ignored in the design of bakery ovens. About ten years ago, designers began to realize the importance of free and forced convection, which led to much experimental and theoretical investigation. In fact, it is because of forced convection that the capacities and flexibilities of the modern baking oven are possible today. Convection depends on many variables, and it has been only in the last few years that experimentation has provided the necessary facts to enable the engineer to calculate and estimate its effectiveness. Some of the important variables that must be considered in predicting heat transfer by forced convection are fluid density, viscosity and velocity. The size, shape, temperatures and surface of the object around which the fluid is forced is important. Forced convection has improved oven efficiencies because the heat is *extracted from* the radiator more effectively and is *transferred to* the product more effectively.

It should be noted when discussing oven heating systems that the terms "indirect" and "direct" refer to location of the products of combustion of the burner system and not to the radiator itself. The radiation is, of course, direct to the product in Fig. 124, but the products of combustion are recirculated through the radiator tubes, and therefore, do not come in direct contact with the product. In the direct type of heating system, the products of combustion are recirculated either naturally or by induced agitation directly through the baking chamber and come in direct contact with the product.

Figure 124 shows a cross-section of a tray oven employing the indirect radiation type of heating system.

Figure 125 shows a direct natural convection type of heating system with ribbon burners.

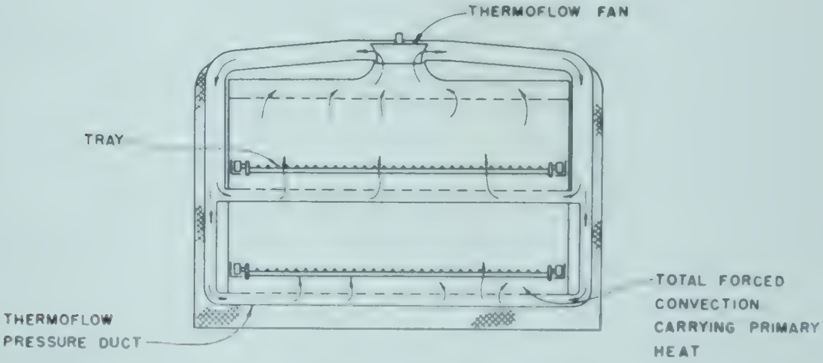


Fig. 128. A Forced Convection Direct Heating System

Figure 126 shows the combination of indirect radiation and forced convection.

Figure 127 shows a plan of an indirect heating system, showing the heater body, radiator and tubes.

Figure 128 shows a cross-section of a forced convection direct (gas) heating system.

Many different types of fuels have been used in the heating systems in bakery ovens. These include wood, coal, peat, oil and gas. Oven heating systems have been devised utilizing electrical energy in localities where power was cheap. Today 99 per cent of all bakery oven heating systems operate with gas or oil.

The burners most popular are the "gun" type or positive pressure atomizing oil burner, the negative pressure or "suction" type gas burner and the tube or ribbon type gas burner. The indirect system shown in Figure 127 is used in conjunction with the single oil or gas burners mentioned above. Each system, composed of a heater, fan and single burner can have a capacity of 500,000 to 3,500,000 B.t.u. per hour. A tunnel oven or single lap tray oven uses up to 4 or 5 of these single burner systems.

The ribbon burner is used in multiple combinations. An air header and a gas header feed from 5 to 15 burners, each with a capacity of 10,000 to 60,000 B.t.u. per hour. These burners can operate on propane, butane or methane gas. Bakery ovens often require as many as 8 or 10 headers or banks of ribbon burners.

Although the oven hearth functions primarily as a part of the mechanical conveying system used to transport the product through an oven, its role as a conductor is equally important when discussing heat transfer. The baking hearth can be thought of as a continuous or semi-continuous baffle between the heating system and the product. It provides a means of controlling the rate of conduction, the effectiveness of radiation and the degree to which convection can be utilized. The type and amount of material used in the hearth determines the rate of heat transfer through conduction. It is for this reason that products requiring a slow bake with a maximum of top heat and a minimum of bottom heat use solid steel, transite or soapstone hearths. Because the solid hearth baffles off most of the heat available through radiation when the radiator is located under the hearth, it is necessary to provide an auxiliary radiator above the hearth to augment the heating system. In order to be most effective, forced convection should be used in conjunction with open grid hearths. Local agitation is sometimes used in solid hearth ovens to overcome tendencies toward hot spots. Normally, this should not be necessary.

Table 74 indicates some of the various materials used for solid baking hearths and their respective "k" factors (average values in B.t.u./°F./sq. ft./hr./in.).

TABLE 74

HEAT TRANSFER ABILITY OF MATERIALS USED FOR HEARTHS

Material	"k" Factor	Thickness Used	Available Heat Transfer
Steel	300	3/16	1000
Carborundum	110	3/4	145
Transite	9	1/4	36

Basic Baking Oven Calculations

Many bakery and allied trade handbooks list a value as the theoretical number of B.t.u. required to bake a pound of bread. It is impossible to arrive at any such *single* figure. The reason for this is fairly obvious. The calculation of a theoretical figure depends on seven values of which only two are fixed. These are the latent heat of vaporization and the specific heat of water vapor (which varies slightly with temperature). The other values are all variables that depend on local conditions, type of flour, type of oven and methods of operation. These are specific heat of dough, temperature of dough into oven (proof temperature), of bread out of oven, oven temperature and percentage of moisture loss.

Let us assume a set of bakery conditions operating with a high proof temperature, low baking temperature and a resulting low baking loss:

Specific heat of dough	0.74
Specific heat of water at 350°F.—(average value)	0.51
Latent heat of vaporization, B.t.u./lb.	970.0
Temperature dough in, °F.	110.0
Temperature bread out, °F.	212.0
Oven temperature, °F.	425.0
Per cent moisture loss	8.0

Then:

Heat for dough = 1 × 0.74 (212–110) =	76.0
Latent heat = 0.08 × 970 =	77.5
Superheat = 0.08 × 0.51 (425–212) =	8.7
	162.2 B.t.u./lb.

Now let us assume a different set of conditions with a low temperature proof, a high temperature bake and a resulting high baking loss:

Specific heat of dough	0.74
Specific heat of water at 350°F.—(average value)	0.51
Latent heat of vaporization, B.t.u./lb.	970.0
Temperature of dough in, °F.	80.0
Temperature of bread out, °F.	212.0
Oven temperature, °F.	525.0
Per cent moisture loss	14.0

Then:

Heat for dough = 1× 0.74 (212–80) =	98.3
Latent heat = 0.14 × 970 =	136.0
Superheat = 0.14 × 0.51 (525–212) =	22.3
	256.6 B.t.u./lb.

It can be seen now that no theoretical value for B.t.u. required per pound of baked bread can be established unless all of the above-mentioned conditions are fixed. We do know, however, that we can reasonably expect the value to lie somewhere between 150 and 250 B.t.u./lb.

It has been determined over the years by extensive field tests that certain types of ovens are capable of producing a certain amount of product. This figure became known as the oven rating or oven loading and is expressed as pounds of bread per square foot of hearth area per hour. It is important to know whether the oven rating is in terms of "baked bread" or "dough." If a rating of 7.0 lbs. bread/sq. ft./hr. is indicated, then it is understood that 7.0 lbs. plus the loss in moisture could be handled by the oven. The baker usually specifies his requirements in terms of baked bread, but the designer must take into account the additional ten per cent of water that is not included with the baked bread weight. Some normal ratings are indicated below:

Plate tunnel	6.0
Grid tunnel–indirect	6.5
Grid tunnel–direct	7.0
Solid hearth tray	5.5
Grid tray–indirect	6.5
Grid tray–direct	6.7
Grid tray–indirect with forced convection	7.2
Grid tray–direct with forced convection	7.2

These values are used as a quick check as to the reasonable expected capacity of an oven. They can also be used to determine the maximum capacity of the burner or burners. Usually, the amount of product that can be physically loaded on the oven hearth and run through the oven at an average baking time will be less than that indicated by the oven rating value.

The oven rating value together with the B.t.u. per pound value plus losses make it possible to determine the total heat load of the oven. Although it would be possible to determine flue losses, stack losses, radiation losses and pan losses by calculation, many assumptions would be necessary. For this reason, it is standard practice to use an overall B.t.u. requirement per pound of dough based on actual field test. Again, many tests on all types of ovens have provided figures ranging from 1,000 B.t.u. per pound down to 325 B.t.u. per pound. The higher values were obtained on ovens of older design. It is reasonable to expect a bakery oven of the latest design to produce open top bread with 325 to 400 B.t.u. per pound. In order to provide some safety factor, a value of 500 B.t.u. per pound is usually used. The actual tolerance provided in this safety factor depends on the proof temperature expected as explained previously.

The scope of this book does not permit an explanation of the calculations involved in both the indirect and direct types of heating systems. For this reason, the indirect design only will be considered because of the more interesting engineering principles involved.

With the total heat load of the oven established, it is possible to design the heating system. Many different procedures are possible, but the most straightforward and easily understood method entails the following:

(1) Determination of burner requirements
(2) Determination of circulating fan size
(3) Radiator design
(4) Determination of forced convection fan size
(5) Check on heat available from radiation
(6) Check on heat carried by forced convection

A sample problem will better explain these terms.

Determination of Burner Requirements

Given:	Oven rating	7.0 lbs./sq. ft./hr.
	Overall loaf requirements	500 B.t.u./lb.
	Number of oven trays	40
	Size of oven trays	24 in. × 121 in.

Then: $$40 \times \frac{24 \times 121}{144} \times 7.0 = 5{,}650 \text{ lbs./hr.}$$

$$5{,}650 \times 500 = 2{,}820{,}000 \text{ B.t.u./hr.}$$

Maximum gas burner requirements $$\frac{2{,}820{,}000}{1000} = 2{,}820 \text{ cu. ft. } CH_4\text{/hr.}$$

Maximum oil burner requirements $$\frac{2{,}820{,}000}{135{,}000} = 20.9 \text{ gallons light oil/hr.}$$

Determination of Circulating Fan Requirements

Given:	Total B.t.u. required/hr.	2,820,000
	Δt over tube length	200°F.
	Specific heat of air at 500°F.	0.248 B.t.u./lb./°F.
	Volume of air at 500°F.	24.2 cu. ft./lb.
	Velocity through tubes	3,500 ft./min.

(1) Weight of air required:

$$\frac{2{,}820{,}000}{0.248 \times 200} = 56{,}900 \text{ lbs./hr.}$$

(2) Volume of air at 500°F.

$$\frac{56{,}900}{60} \times 24.2 = 22{,}900 \text{ cu. ft./min.}$$

(3) Cross section area tubes

$$\frac{22{,}900}{3{,}500} = 6.55 \text{ sq. ft.}$$

The Δt over the tube is based on an inlet header temperature of 750°F. and an outlet header temperature of 550°F. These are average figures and will vary with the velocity through the tubes. The greater the velocity, the lower the Δt. This would indicate that in order to produce a high and apparently efficient Δt, low tube velocities would be desired. This is not the case! Too high a Δt will cause unnecessary and undesirable hot spots and shorten the life of the heater body and firing tunnel. Indications are that a Δt between 175° and 250°F. produces the best baking results and greatest oven efficiencies. Tube velocities between 3,000 and 4,000 ft. per min. will produce the required Δt in the conventional indirect heating system.

Design of Radiators.—One general statement could be made concerning the design of the radiators and the duct work leading to and from them:—follow accepted air conditioning duct work standards! Naturally, all such general statements are subject to some exceptions and bakery oven radiator design is no different.

The first and most important is the sizing of duct work and radiators. Normally, air conditioning duct work will be reduced in cross section as the run is lengthened to compensate for skin friction and loss in static pressure. The design of oven duct work must consider not only this factor but also the reduction in volume because of the high temperature drops (as compared with air conditioning duct work). Generally, it is desirable to maintain fairly uniform velocities through the system, and, therefore, volume compensations are considered good practice. Remember, however, that the weight of air circulated is constant.

One of the greatest problems in oven design is the effective control of lateral heat. The best way to insure even lateral heat is to feed the inlet radiator from both sides. It is advisable to return the gases from the outlet header from both sides also, although if some compromise is necessary, the return header is the first choice. Along with proper feed goes adequate adjustment. Regardless of the adequacy of the duct system, sufficient and effective air flow adjustments are essential. Local conditions and other unpredictable variables make field adjustments necessary. Whether they are internal or external adjustments is not important. The main thing is that they are provided.

All ducts should be kept as round or square as possible. If a rectangular duct is necessary, it must be made proportionately larger than an equivalent square or round duct according to fan and duct standards. The inside corners of elbows should be made with a radius, if possible. Forty-five degree bevels are acceptable, but under no circumstances should a 90° break be used. The outer portion of the elbow can be any shape. A radius here would be most expensive and of no practical value. The air traveling inside of a 90° outside elbow surface will form its own effective, curved surface by a build-up of stagnant air without reducing air flow efficiency.

Adequate allowance should be provided for thermal expansion of the duct work. Radiator headers should be free-floating with fixed tubes or fixed headers with floating tubes. Completely internal ducts will follow the principles of thermal expansion, but any longitudinal ducts bolted rigidly to external cross supports will expand much less.

The last point to discuss is the use of stay rods. Most ducts are made of 14, 12 or 10 gauge sheet steel and must have enough strength not only to support themselves but also to resist permanent deformations by normal positive or negative pressures. Even though protected by the most up-to-date flame safeties, a burner will occasionally backfire. To protect the system against deformation from minor backfires and the corresponding pressure build-up, stay rods or tie rods are welded between the top and bottom sheets. These vertical supports also eliminate any snapping and cracking of the ducts during heating and cooling periods.

Heat Available from Radiation.—When designing a radiating system for a baking oven, it is necessary to keep checking and rechecking to be assured of a reasonable balance of all factors. The physical size of the oven governs, to some extent, the size and number of radiator tubes, and yet the tube velocities are also a function of these two variables. Further, the available radiation is a function of the number and size of the tubes, assuming that sufficient air is circulated through the tubes to maintain the required tube temperature. It must be remembered at all times that the primary function of the bakery oven is to bake bread, and that the heating system must not only supply heat but must supply it in the right amount, in the proper space, at the proper location and at the correct time. Any compromise of these four requirements will produce less than satisfactory results.

Once the amount of recirculated air is determined and the cross-sectional area established, the size and number of radiating tubes can be fitted into the space available in the specific oven in question, and a trial expected heat release calculated.

This can best be accomplished by the formula:

$$q = 0.174e\left(\frac{T}{100}\right)^4$$

where q = B.t.u. radiated per hour, per square foot of radiating area,
$e = 0.79$, radiation emissivity for oxidized steel
$T = t + 460°\text{F.}$, surface temperature in degrees absolute

Thus, a tube at an average temperature of 700°F. has the capability of radiating,

$$\begin{aligned} q &= 0.174 \times 0.79 \times 10^{-8}\ (700 + 460)^4 \\ &= 0.1376 \times 10^{-8}\ (11.6 \times 10^2)^4 \\ &= 0.1376 \times 11.6^4 = 2{,}480 \text{ B.t.u./sq. ft./hr.} \end{aligned}$$

The radiating system for an oven having a capacity of 5,650 lbs./hr. should thus have a *minimum* of,

$$\frac{2{,}820{,}000}{2{,}480} = 1{,}138 \text{ sq. ft. of radiation area}$$

including the cross headers.

It should be noted that a high average of 700°F. over the radiating system is used along with the high B.t.u. requirements of 2,820,000. This latter figure already allows for a reasonable margin of safety in the system so there is no need to extend the safety factor over the radiating system. Actually, during operation the 2,820,000 B.t.u./hr. consumption will never be reached, and the average tube temperature will be somewhat less than 700°F.

A spacing of at least one inch should be allowed between tubes to permit unrestricted flow around the tubes. These longitudinal tubes should cover a lateral area across the oven the same width as the tray. In our example, the tray was given as 24 inches × 121 inches.

This allows the choice in a single row system of,

$$\frac{121}{4+1} = 24\text{–}4 \text{ in. } \phi \text{ tubes}$$

$$\frac{121}{5+1} = 30\text{–}5 \text{ in. } \phi \text{ tubes}$$

$$\frac{121}{6+1} = 17\text{–}6 \text{ in. } \phi \text{ tubes}$$

the minimum length of tube required to give the required surface area of 1,138 sq. ft. would be,

$$\begin{aligned} 24\text{–}4 \text{ in. } \phi &= 46 \text{ feet} \\ 20\text{–}5 \text{ in. } \phi &= 44 \text{ feet} \\ 17\text{–}6 \text{ in. } \phi &= 42 \text{ feet} \end{aligned}$$

so that from the length requirement, any of the three tube sizes would be reasonable.

Now, let us examine the cross-sectional area. First of all, it can be assumed that whether a single lap or a double lap is being designed, an oven of this size will require four radiators. These radiators will be at least twelve feet long. The cross-sectional area of the tubes should be $6.55/4 = 1.64$ sq. ft. to obtain a tube velocity of 3,500 ft./min.

The cross-sectional area of the three sizes is:

24–4 in. ϕ (round) = 1.9 sq. ft.
20–5 in. ϕ (round) = 2.6 sq. ft.
17–6 in. ϕ (round) = 3.06 sq. ft.

At first glance, it would appear that even the 4-inch diameter tube is too large, but this is not necessarily true. It is possible to reduce the cross-sectional area and maintain the surface area by flattening. This operation also causes a turbulence in the tube which reduces any tendencies toward stratification and also lowers the film coefficient along the tube. These new areas are:

24–4 in. ϕ (flattened 50 per cent)–1.45 sq. ft.
20–5 in. ϕ (flattened 50 per cent)–1.8 sq. ft.
17–6 in. ϕ (flattened 50 per cent)–2.25 sq. ft.

The choice would be either the round 4-inch diameter tubes with a velocity of 3,000 ft./min. or the flattened 5-inch diameter tubes with a velocity of 3,200 ft./min. Either would be acceptable.

Determination of Amount of Forced Convection.–The application of forced convection in baking ovens is not new, but it is only within the last ten years that serious consideration has been given to its effect on the various bakery products. For some time, it was felt that any amount of agitation would reduce hot spots, even out lateral heat and provide better heat transfer to the loaf. Eventually, the need for more complete and serious testing became obvious. Although laboratory tests were helpful, it was necessary to substantiate the results in full scale baking ovens operating under normal production conditions. These laboratory and field tests pointed out two very definite conclusions. Volume and velocity of the forced convection air are the key factors. Although location of the jet streams was once considered the most important factor, it was found that when the correct volume of baking chamber air was recirculated at the correct velocity, there was little change in results when the air was directed downward onto the product or upward around the product. The most practical application is from the bottom upward. This allows for maximum utilization of any free convection currents.

It is essential that the optimum volume of convected air be varied as the type of oven and the capacity are varied. One of the best ways to state the volume requirements is in terms of cubic feet of free air per square foot of hearth area. The optimum figure is from 12 to 25 cu. ft./sq. ft. The optimum velocity is from 2,500 to 4,000 ft./min. from the plenum. The relation between the two depends upon the basic oven design and the type of product to be baked.

In the example, let us assume a forced convection requirement of 22 cu. ft./sq. ft. hearth area at 3,600 ft./min.

Then, $40 \times (24 \times 121/144) \times 22 = 17{,}700$ cu. ft./min.

Two or three fans should be used to keep the size down and provide flexibility in control. It is essential that the fans feed the bottom plenum in the center or from both sides. Velocity drops up to 50 per cent can be expected across the oven in plenums fed from one side only.

Heat Carried by Forced Convection.—Even though the basic radiation system should be capable of supplying enough heat for the maximum production expected, it is very helpful to have some idea as to how much extra heat transfer is obtained from the additional forced convection. A method of calculating this will be shown for one bottom radiator in our example:

Given

Number of tubes	24	Surface area	300 sq. ft.
Diameter	0.333 ft.	Area between tubes	24 sq. ft.
Length	12 ft.	Volume of convected air	8,850 cu. ft.

Then, the velocity around the tubes will be,

$$\frac{8{,}850}{24} = 369 \text{ ft./min.} = 6.15 \text{ ft./sec.}$$

An overall heat transfer coefficient can be obtained from the following equation:

$$\frac{Ul}{k} = K\left(\frac{vl\rho}{\mathrm{N}}\right)^{-e}$$

where Ul/k is Nusselt's number, and $vl\rho/\mathrm{N}$ is the Reynolds number, K and e being forced air constants.

The values are:

U = overall heat transfer coefficient, B.t.u./hr./sq. ft./°F.
l = tube diameter in feet, -0.333
k = thermal conductivity of air, in B.t.u./hr./sq. ft./°F. at temperature, -0.0224
K = forced air constant, for tube > 2 inch O.D., -0.282
v = velocity air around tube, ft./sec., -6.15
ρ = density air around tube, slugs/cu. ft. at temperature of media
μ = viscosity of air around tube, slugs per sec./sq. ft./ft. at temperature, -0.564×10^{-6}
$-e$ = forced air exponent, for tube >2 in. O.D., -0.585

Calculate ρ from,

$$PV = wRT$$

$$\rho = \frac{w}{gV}$$

$$\rho = \frac{P}{gRT}$$

$$\rho = \frac{14.7 \times 144}{32.2 \times 53.3 \times (460 + 500)} = 0.00128$$

Then,

$$\frac{Ul}{k} = \frac{0.282\ (6.15 \times 0.333 \times 0.00128)^{0.585}}{0.564 \times 10^{-6}}$$

$$= 0.282\ (4{,}650)^{0.585}$$

$$= 0.282 \times 140 = 39.5$$

and,

$$U = \frac{39.5 \times 0.0224}{0.333} = 2.66 \text{ B.t.u./hr./sq. ft./°F.}$$

Further, given that

Average tube temperature	650°F.
Baking chamber temperature	450°F.
Δt around tube	200

Q = B.t.u. available
a = area tubes, one radiator 300 sq. ft.
$Q = Ua\Delta t$
$= 2.66 \times 300 \times 200 = 159{,}000$ B.t.u./hr.

This radiator should thus be capable of radiating 300 × 2,480 = 794,000 B.t.u./hr. and giving up 159,000 B.t.u./hr. to the air circulated around it. It must be realized that some of the above values are assumptions based on field tests and that they can vary. The important idea is that 20 per cent more heat can be extracted from the conventional radiator system by the addition of forced convection. It is this added efficiency that has helped to make the tray ovens and the indirect heating system as popular and successful as they are today.

Measuring the Effectiveness of Baking Ovens

No matter how good a design looks on paper, the ultimate decision as to effectiveness can only be made after field tests. Besides the appearance and taste of the baked loaf, there are several more specific tests that can be made. The first is the determination of the number of B.t.u. required to bake a pound of a specific product.

The test is quite simple, but as explained previously, the variable factors in the equipment ahead of the oven must be considered in the final analysis of results. Remember that the hotter the proof box, the more efficient the oven will appear. A baking test should be made on a full oven that can be run continuously on one product for at least one hour. There should be a separate gas meter for the oven if the fuel is gas, and a means for weighing oil if the fuel is oil. It is necessary to use the average scaling weight, obtained by periodically checking the weight

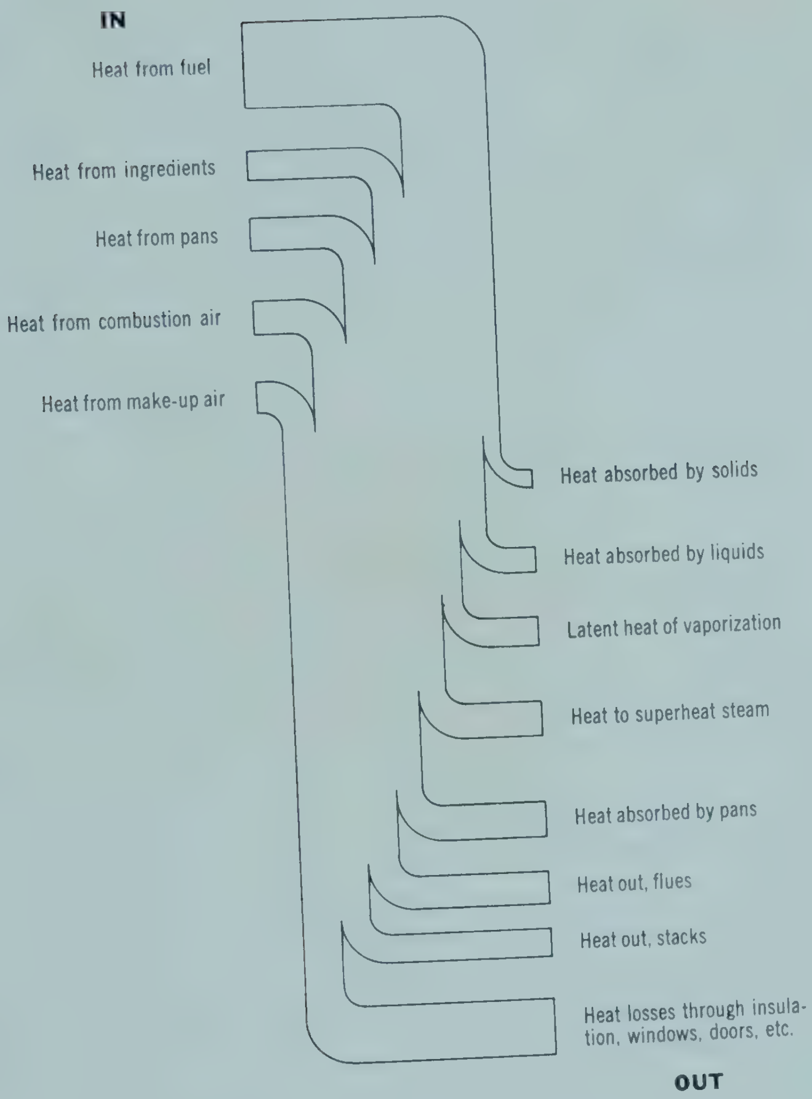

IN
Heat from fuel
Heat from ingredients
Heat from pans
Heat from combustion air
Heat from make-up air
Heat absorbed by solids
Heat absorbed by liquids
Latent heat of vaporization
Heat to superheat steam
Heat absorbed by pans
Heat out, flues
Heat out, stacks
Heat losses through insulation, windows, doors, etc.
OUT

FIG. 129. DIAGRAMMATIC REPRESENTATION OF HEAT BALANCE

at the divider, to determine the overall product weight over the test period. Never take anyone's word for scaling weight. The total pounds of product run through the oven, divided into the total of B.t.u. used, give the B.t.u. required per pound of *dough*. This figure includes all oven losses and inefficiencies so it can be considered a true measurement of an oven's effectiveness. It is readily seen that to obtain the best results, the burner must be carefully adjusted, all doors closed, all insulation solid and intact and the oven fully loaded.

At times, it is desirable to carry the test further and obtain the B.t.u./lb. of *baked bread* and a heat balance over the oven. This requires a bake-out test which should be run at the same time as the efficiency test. The bake-out test is made to determine how much water vapor and other volatile gases are evaporated from the loaf during the baking process. The dough pieces should be individually weighed if any degree of accuracy is expected in this test. The usual procedure is to weigh four dough pieces at the moulder and hand pan them, marking each piece. Weigh enough pieces so that a pan set can be located at the left, center and right of at least two oven trays. The samples should be at least three trays apart. These sets are then unloaded, and the individually marked loaves are again weighed on the *same* scale. The difference in weight, divided by the original weight, multiplied by 100 is the bake-out loss in per cent. This figure should vary between 7 and 12 per cent for open top bread, depending on the type of oven and the baking time. Normally, the faster the bake, the lower the bake-out losses.

If, at the same time the bake-out and oven efficiency tests are run, other data are recorded, a heat balance can be run over the oven. The data required are: pan set weight; stack temperature; stack gas velocity; flue temperature; and flue gas velocity.

From these data, the heat balance can be made as diagrammatically shown in Fig. 129.

It has been pointed out that proof temperatures should be carefully noted when running oven performance tests. It is also advisable and interesting to note the cooling temperatures and losses. Moisture losses do not stop at the oven. They continue on through the cooler, regardless of type, though to a much lesser degree. Although sufficient evidence has not been gathered to date, there is every indication that overall moisture losses are constant. This means that if the oven loss were 7 per cent, the cooler loss would be high, perhaps around 4 to 5 per cent. If, however, the oven loss were 10 per cent, the cooler loss would only be 2 per cent. There have been indications of this concept but not under controlled test conditions.

Mechanical Design Factors

Expansion Joint Design.—Correct allowance for expansion is a vital factor in the smooth mechanical operation of any oven. The design of the heating system, conveyor system and oven shell must all take into consideration thermal expansion. As previously stated, actual expansion does not follow expansion rule directly because of the varying number of through support members. A 100-foot oven should expand approximately 3.2 inches when being heated from room temperature to 500° F. In practice it is found that this size oven will actually expand from 1.25 to 1.5 inches.

There are two basic ways to allow for thermal expansion. The first is to anchor both ends to the floor and allow the expansion to move through slip joints toward the center. In this design, one slip joint should be provided for every 20 to 30 feet of oven length. The second is to anchor one end only and allow the whole oven to expand from this point.

The first design allows both ends to be stationary, which is required in tunnel oven design using automatic loaders and unloaders. It does require extreme care in the manufacturing and assembling of the slip joint so that it will function properly and yet still be steam tight. The second design is most practical with tray ovens where loading and unloading are done at the same end. Care must be taken in the design of the vertical support members so that free and easy horizontal movement can be obtained. The importance of proper expansion allowances cannot be stressed too strongly. Most mechanical problems in oven design can be traced to inadequate handling of an expansion problem.

Determination of Conveyor Drive Requirements.—There are many different ways to calculate horsepower requirements for a conveyor. The most significant manner in which they vary is the assumption of chain friction and bearing friction figures. It has been fairly well accepted that bearing losses due to friction will be between 5 and 10 per cent. The chain friction coefficient is also between 5 and 10 per cent. In order to obtain more reliable figures, tests have been made which allowed measurement of the actual chain pull (in pounds) between the drive motor and the oven conveyor sprocket. Figures were obtained on enough sizes of ovens with enough different loads so that curves could be plotted. The oven chain pull could thus be predicted for any size oven. This figure included chain and bearing friction. It was thus possible to calculate what the total of the two coefficients would be. It was further possible to predict what the chain coefficient would have to be if a bearing coefficient were assumed. Two methods of calculating horsepower requirements will now be explained; the first, using theoretical methods; the second, using the measured values.

In our oven design example, there were 40–24 in. × 121 in. trays. We are further given:

Weight of tray	120 lbs.
Weight of grid	60 lbs.
Weight of product and pans/tray	240 lbs.
Chain roller diameter	2.5 in.
Chain weight per pitch	3 lbs.
Coefficient rolling friction, steel to steel	0.10
Weight of load per tray roller	420/4 = 105 lbs.
Pitches per tray	5

Then from,

$$F = \frac{f_r P}{r}$$

where,

F = force to overcome rolling friction
f_r = coefficient of rolling friction
P = load in pounds
r = radius of roller in inches

Force to move trays only,

$$F = \frac{f_r P}{r} = \frac{0.10 \times 105}{1.25} = 8.4 \text{ lbs./tray roller}$$

Then,

$$8.4 \times 40 \times 4 = 1{,}345 \text{ lbs. to move trays only}$$

Force to move chain only,

$$F = \frac{0.10 \times 3}{1.25} = 0.24 \text{ lbs./chain roller}$$

Then,

$$0.24 \times 200 \times 2 = 96.0 \text{ lbs. to move chain only}$$

$$\text{Force to move conveyor} = \begin{array}{rl} 1{,}345 \text{ lbs.} & \text{—trays} \\ 96 \text{ lbs.} & \text{—chain} \\ \hline 1{,}441 \text{ lbs.} & \text{—10 per cent for bearings} \\ \hline 1{,}585 \text{ lbs.} & \end{array}$$

$$\text{Torque at oven sprocket} = 1{,}585 \times \frac{20.22}{2} \text{ p.d.} = 16{,}050 \text{ in. lbs.}$$

Oven sprocket maximum speed = 2.6 r.p.m.

$$\text{h.p.} = \frac{T \times \text{r.p.m.}}{63{,}000} = \frac{16{,}050 \times 2.6}{63{,}000} = 0.66$$

From the experimental data, the predicted chain pull on an oven this size should be 1,280 lbs., which would give a horsepower requirement of. h.p. $= 1{,}280 \times 20.22/2 \times 2.6/63{,}000 = 0.54$.

From these figures it can be seen that a 1 or $1\frac{1}{2}$ horsepower gear head motor unit would be adequate for this oven.

Oven Chain.—Today the selection of oven conveyor chains is not considered to be a problem. There are any one of 4 or 5 very satisfactory hollow pin bushed roller chains available. The hollow pin chain has won universal acceptance because of the ease with which trays can be secured.

It must be remembered that the purpose of an oven chain is not primarily one of transmitting power as is usually the case. In the baking oven, the chain is also used to carry or move the baking plates or oven trays.

The hollow pin chain has sufficient strength, a long life expectancy when properly cared for and is easy to maintain. The extremely slow movement and high temperature are the main requirements that void the use of precision roller chains. This is because the close tolerance of the precision roller chain does not allow adequate penetration of the chain lubricant.

In selecting an oven chain, one has the choice of short pitches, 2 to 3 inches, or long pitches, 4$^1/_2$ to 9 inches. Each has its advantages. The short pitch chain has less articulation around the sprocket than the long pitch, which allows smoother operation.

There have been many discussions concerning comparative pitch elongation or wear of short and long pitch chain. No conclusive answers are available, but theoretically there should be no difference. A three-inch pitch chain will have twice as many wear points as a six-inch pitch chain, but the only place bushing wear can occur is around the sprocket. If the pitch diameters are the same, the three-inch pitch chain will articulate half as far as the six-inch pitch chain and thus wear half as much per pitch. The total elongation due to wear should thus be the same for equal length chains.

The question of strength often arises. It was shown in the preceding sections that oven chain pulls of 500 to 1,600 lbs. could be expected, and yet oven chains are expected to have an ultimate strength of 24,000 lbs.

Assuming the same spacing is desired between runs, the short pitch chain will allow less differential between sprocket pitch diameters when building oven shells to accommodate more than one tray size.

The long pitch chain is easier to maintain because there are fewer lubrication points. Larger rollers can be provided, which means it will require less turning effort, and theoretically, less horsepower. Long pitch chains can accommodate larger tray pins which become more important as trays get wider and loads get heavier. Whatever the selection is, it must be done with full knowledge of all the facts. Today, the long pitch chain has received the most acceptance.

A discussion on oven chain would be most incomplete without mentioning lubrication. The success of the mechanical bakery oven was dependent on finding a suitable oven chain lubricant. Although chains had been used in bake ovens in the steel, automotive and other similar industries, it was accepted practice to replace rollers and often complete chains as frequently as every year. This was not practical in one-oven bakery operation, because the whole shop would be tied up during the changeover. Then, too, it was an extremely expensive repair. After many years of experimenting and field tests, it was found that most suitable lubricant was a suspension of superfine graphite in a high grade kerosene. The graphite provides the actual low friction medium between the chain roller and the bushing and between the bushing and the hollow pin or stud. The kerosene vehicle carries the graphite into the areas to be lubricated and then vaporizes, leaving a very minimum of residue.

Other lubricants have been developed recently, utilizing water as a vehicle. Molybdenum disulfide is used as the lubricant. This lubricant is cleaner than graphite and produces practically no fumes when vaporizing. The comparison in lubricating properties between graphite and molybdenum disulphide is not yet conclusive. Unfortunately, the final analysis can be made only after 3 to 5 years of field test. Many lubricants have been tried, only to fail after several years of continued application. No grease has yet been found that does not have to be periodically replaced with fresh grease. The final result has always been carbonization and scoring of the rotating parts.

One of the changing ideas in lubrication is that "once a week" is frequent enough. This was true when ovens were operated at slow speeds for 40 or 50 hours per week. Now that speeds have almost doubled and operation periods have more than doubled, it is necessary to lubricate the chain at least once every 40 hours of operation. No lubrication should be attempted unless the oven is cooler than 275° F. If lubrication is done at temperatures higher than 275° F., the vehicle evaporates almost upon contact, and no penetration is achieved. The lubricant is wasted, the mechanic's time is lost and damage can occur to the insufficiently lubricated chain.

Tray Stabilization.—One of the factors that insured the success of the tray oven was the complete stabilization of the trays. This provided more trouble-free operation, allowed for automatic loading and unloading and permitted a greater variety of products to be run through the ovens.

There are essentially three basic methods of tray stabilization. The first is the internal cam and guide roller method, as shown in Fig. 130.

The second is the third chain, illustrated by Fig. 131.

The third is the diagonally supported, staggered chain, shown in Fig. 132.

They are all tried and proved methods. The internal cam is the most economical but must be perfectly machined and adjusted to prevent vibration. There is a transfer of control which makes perfect stabilization most difficult. The third chain method relies on the torsional strength of a crank arm and chain pin to maintain stability, and with heavier loads and larger trays becoming necessary, its limitations are being approached.

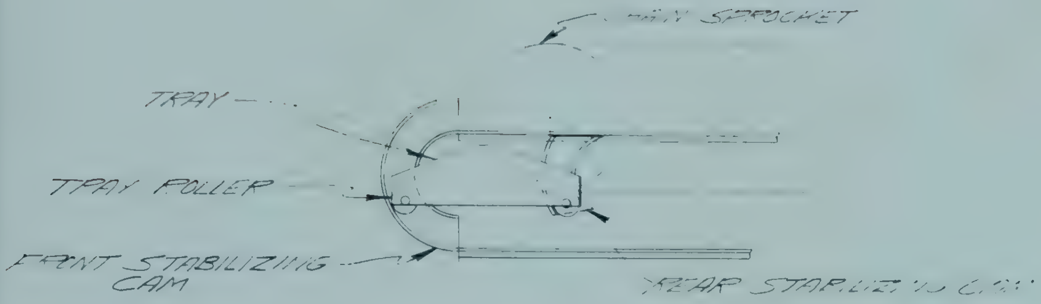

MAIN SPROCKET
TRAY
TRAY ROLLER
FRONT STABILIZING CAM
REAR STABILIZING CAM

FIG. 130. INTERNAL CAM AND GUIDE ROLLER METHOD FOR STABILIZING TRAYS

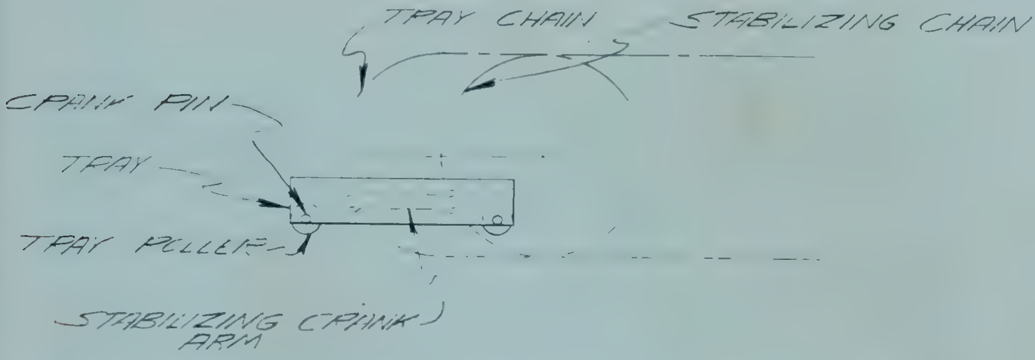

TRAY CHAIN
STABILIZING CHAIN
CRANK PIN
TRAY
TRAY ROLLER
STABILIZING CRANK ARM

FIG. 131. THE THIRD-CHAIN METHOD FOR STABILIZING TRAYS

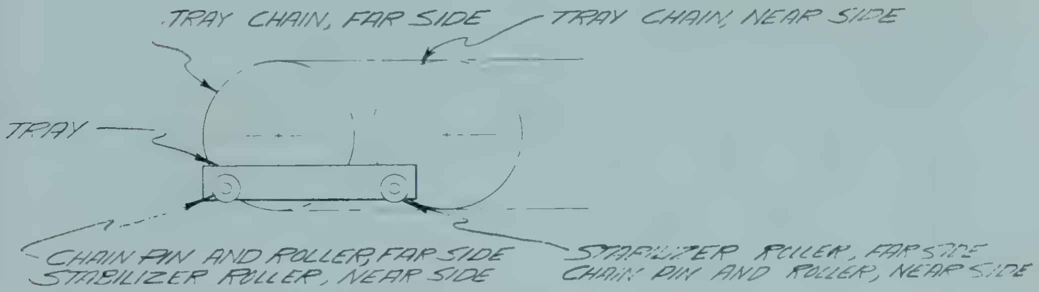

TRAY CHAIN, FAR SIDE
TRAY CHAIN, NEAR SIDE
TRAY
CHAIN PIN AND ROLLER, FAR SIDE
STABILIZER ROLLER, NEAR SIDE
STABILIZER ROLLER, FAR SIDE
CHAIN PIN AND ROLLER, NEAR SIDE

FIG. 132. DIAGONALLY SUPPORTED, STAGGERED CHAIN METHOD FOR SUPPORTING TRAYS

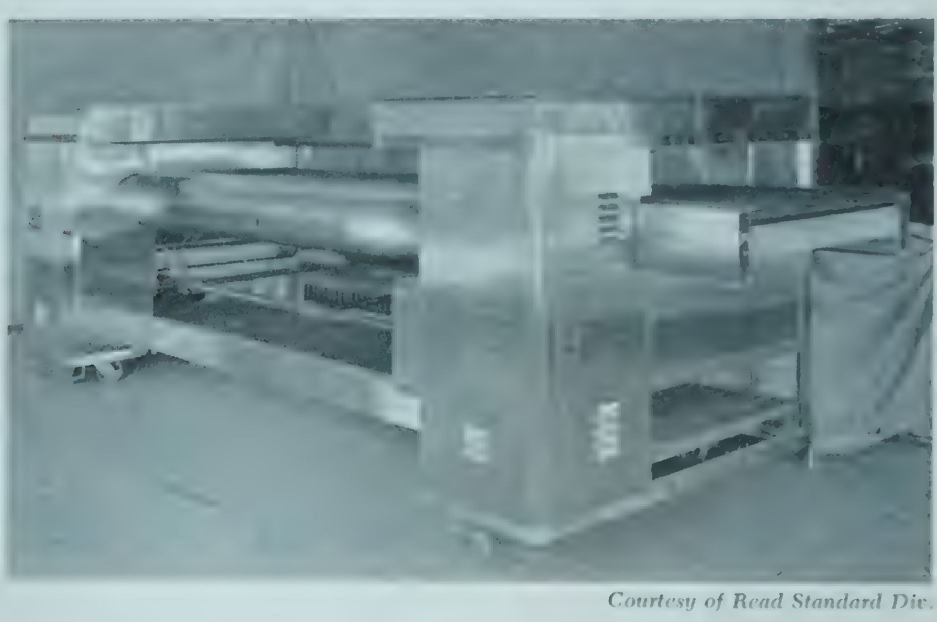
The single chain side is subjected to greater loads than the double chain side with a resulting increase in elongation due to wear.

The last and most expensive method is the staggered chain system. This allows complete and smooth control at all times with a minimum of parts inside the oven. It does require a gear box outside the oven to synchronize the drive sprocket and stabilizing sprocket.

There are other stabilization designs, but they are all modifications or combinations of the ones described above.

Oven Auxiliaries

Loaders.—Just as ovens have grown more automatic and versatile in the past decade, the oven auxiliaries have been redesigned to conform to the requirements of automation. The first so-called automatic loaders did little more than allow the operator to stand away from the heat of the oven and have the pans automatically placed on the oven trays or hearth. The concept of complete automatic plants brought about the design of side fed loaders and automatic groupers or pan spacers. These innovations permit pans to be fed singly onto a conveyor, remote from the oven. The row of pans, regardless of the number in the row, are automatically spaced and metered to the loading area in front of the oven where they are then loaded onto the trays or hearth. The grouping and side loading arrangement can also be fed automatically from the final steam proofer. Most loaders are now made either removable or with a drop-front to permit easy and ready access to the oven.



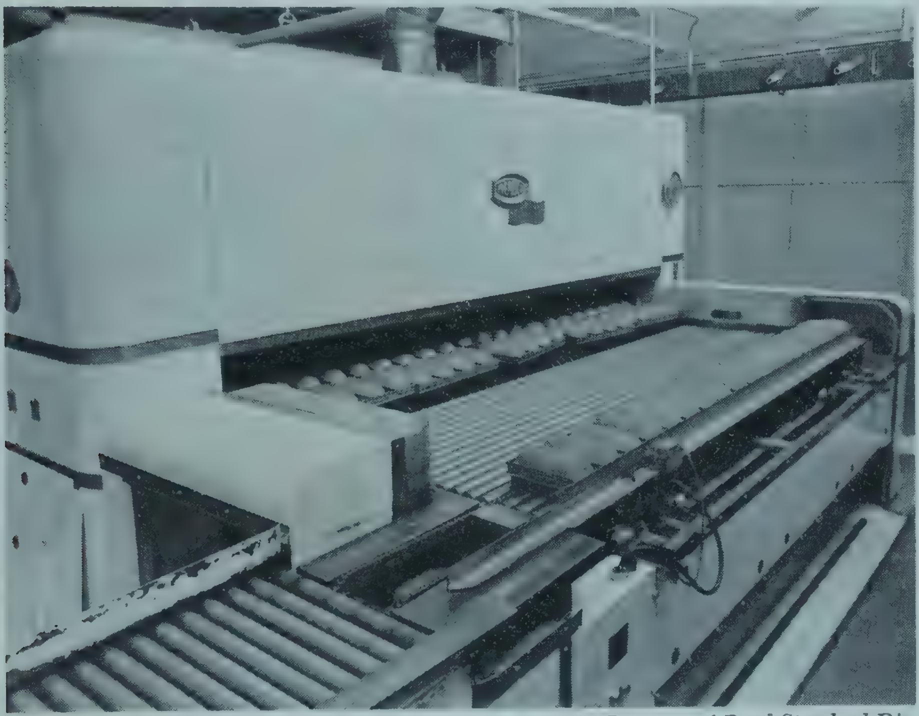
Courtesy of Read Standard Div.

Fig. 133. A Level Plane Unloader for Tunnel Ovens

Unloaders.—The oven unloading arrangements also had to keep pace with increased production demands. For many years, the oven trays or the grids of the trays were tilted so that the pans of baked bread could slide onto a cross conveyor extending outside the oven. The tilting tray unloader is still preferred by many bakers, and the vertically adjustable cross conveyor has minimized the product displacement during unloading. Now, level plane unloaders can pull or push the product horizontally onto a cross conveyor from a level tray without losing control of the pan.

This offers very definite advantages in unloading buns, rye bread and pullman bread. A level plane unloader like that shown in Fig. 133 further offers the advantage of portability and removability, which cannot be designed in a tilt tray unloader.

The advent of the raised wire grid in the tunnel oven has made possible an almost horizontal unloader, utilizing stripper chains or vertically oscillating bars between the oven grid wires. Such an apparatus is shown in Figure 134. The old method of unloading, used by maintaining fluted and smooth lateral rollers, required an uncontrolled pan drop of 5 to 8 inches. The horizontal surface of the newer type of unloader is only $^1/_2$ to 1 inch below the oven hearth level. The product can be removed from the oven straight away, and a complete oven row automatically depanned. The row also can be removed to either side and fed to a single or multiple strap depanner.



Courtesy of Read Standard Div.

FIG. 134. AN OVEN UNLOADER UTILIZING STRIPPER CHAINS

Controls.—Positive and accurate control of the oven drive and the burner system and reliable protection of both is an important part of oven design. Variable speed, continuous drives and intermittent variable pause drives are available with baking times from 6 to 120 minutes. The control instrument can be mounted on the oven or at any convenient location near the oven. In the larger semi-automatic or automatic plants, it is desirable to have the control panels for proofer, oven and cooler located near one another so one operator can observe and control all three units. Besides centralizing the control and reducing man power to a minimum, this compact grouping of the three major units reduces connecting conveyors to a minimum.

Oven temperatures can be measured by use of a thermocouple and potentiometer or a sensitive mercury or mercury vapor-filled bulb and a potentiometer or air-operated temperature indicator. The all-electric systems provide the advantage of obtaining the readings from any number of thermocouples, using only one instrument. The air system proportions, or modulates, the output of the burner according to product demand without any visible "hunting" or oscillating of the control valves. The electric system can be made to modulate the burner control, but "hunting" can occur if careful adjustments are not made. A new feature of the modulating control is the added "off" part of the cycle. Normally, burners are operated on-off, hi-low or modulating. At times, even the low fire is too much for proper temperature control. The development of the modulating and "off" control met this requirement for better control. The use of scanning light beams and photo-electric cells to protect unloading areas from bent pans and other operational irregularities is gaining acceptance. Because of the hot and smoky location of these safety eyes, it is necessary to clean and adjust them quite frequently.

Future Considerations

There can be little doubt that the concept of forced air agitation has been the major contribution to the advancement of baking ovens in the past twelve years. When one realizes that a baking oven is little more than a heated mechanical conveyor surrounded by an insulated box, the future improvements can be seen to lie mostly in the heating system. Although improvements in the mechanical components can be expected, any such improvements would not necessarily improve the production rates or quality of the bake. So far, the rate of heat transfer to and through the product has been the limiting factor Forced convection has improved the rate of heat transfer from the heating system to the product. The speed of heat transmission through the product remains the same. Although many claims have been made for heating systems capable of producing a 14 and 15 minute bread bake, the final acceptance or rejection of the system depends on the somewhat elusive and controversial definition of a "baked" loaf. This definition varies from one section of the United States to another and from one country to another. When one has to consider such variables as color, taste, odor, symmetry, volume, grain size, texture and many others, the difficulty of arriving at a universally accepted definition of "bake" is easily understood.

Some years ago the idea of applying infra-red heat to the bread baking process was proposed and tested to some extent. Since then it has been revived from time to time. Actually bread in pans has yet to be baked faster in an oven utilizing infra-red heat than in an oven with the conventional type of heating system. It is true that the pan itself can be heated somewhat faster with an infra-red heating source, but the heat transfer through the pan and through the loaf must still be accomplished by conduction. To be most effective, the infra-red rays must "see" the loaf directly. Contrary to popular belief, infrared rays do not bake the product from within. This points out the possibility of combining infra-red heaters or burners with conventional radiation tubes or direct fired ribbon burners. Infra-red rays begin to be emitted at temperatures of around 1,400°F. If the temperature falls below this, any possible effects from infra-red baking are lost. The only way to obtain burner turn-down and oven flexibility is by turning certain burners completely off, maintaining the desired reduced temperature with fewer burners turned fully on. Unless the burners are very small and spaced close together, this would create hot and cold spots in the oven. The possibilities of applying infra-red heat in a practical manner are great, but much testing and experimenting will be required.

High frequency heating, while successful in the preparation of some food, has not yet been successfully adapted to bakery products. The field of application is wide open and offers many different and interesting possibilities. A bakery oven employing high frequency baking would no longer be recognized as such. The oven could be extremely small and would require little, if any, insulation. The main questionable factor and potential stumbling block would be the production and retention of the bread flavor.

As long as there are possibilities for improvement, better ovens can and will be built. When all the possibilities are exhausted, Yankee ingenuity will supply more.

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Charles S. McWilliams

Canned Bakery Products

Bread, cakes and sweetgoods bakery products are highly perishable foods readily and rapidly undergoing staling, dehydration, and deterioration because of mold growth. One method of preserving bakery products is canning. This method of preservation is of considerable interest to the Armed Forces in supplying highly acceptable bakery foods to troops in the field and in situations where it is impossible or impractical to operate kitchen or bakery installations. To satisfy this need the Quartermaster Corps has pioneered developmental research on the canning of bakery products. Today, combat rations contain four canned bakery products: (1) white bread, (2) poundcake, (3) fruitcake, and (4) pecan roll.

Two of these products, canned poundcake and fruitcake, enjoy some commercial importance in the civilian economy. These and other canned bakery products potentially have value for feeding civilians in isolated areas (for example hunters in wild areas, explorers, yachtsmen and lighthouse attendants).

Canning offers an excellent method for economical distribution of special dietary breads. Except in areas having very dense populations, the demand for these foods is not sufficiently large to permit supplying them on the same basis as ordinary white bread. Canning will allow storage in, and distribution from, outlets which have a very low turnover. In fact, selling of these specialty items by mail is perfectly feasible. Gourmet items are another class of baked goods which might be adaptable to canning. Most of these potential markets have never been adequately explored.

The manufacture of canned baked products spans two important food industries—the baking industry and the food canning industry. Since the major demands for equipment and "know-how" inherent in the manufacture of these items are found in the baking industry, it logically follows that it is far less difficult to modify and equip a bakery for canning than it is to equip a cannery for baking.

BAKING

The principal modification in manufacturing canned baked products is that these products are baked in tin cans rather than in the customary

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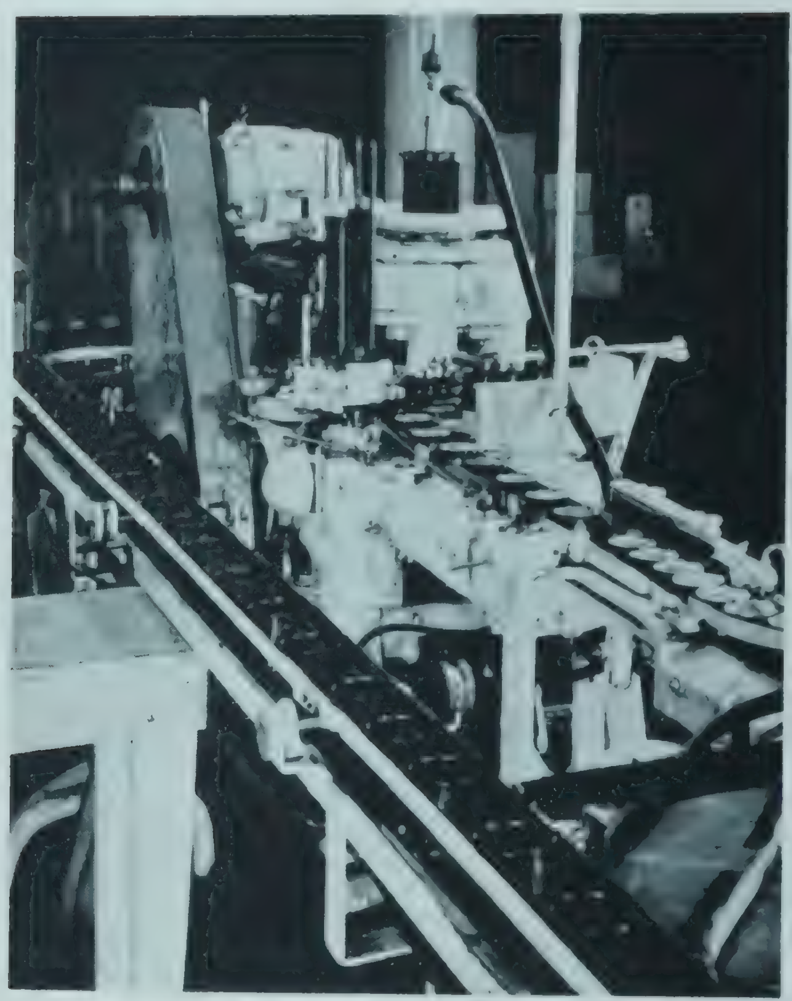


Courtesy of Kroger Baking Co

FIG. 135. CAN LIDS BEING LOOSELY CLINCHED ONTO CANS OF BAKED PRODUCTS PRIOR TO PLACING THE CANS IN THE OVEN

baking pans. Canned baked products utilize standard bakery ingredients and conventional mixing and processing machinery. The resulting dough or batter is deposited into the tin cans and the can lid is then loosely clinched into place by a can-sealing machine (Fig. 135). The loosely-clinched lid permits escape of leavening gases and steam evolved during baking in the standard baking oven (Fig. 136). Canned baked products may be baked in either a tunnel or tray oven; if baked in a tray oven, the use of wire baskets to keep cans evenly spaced during baking is advisable.

CAN SEALING, COOLING, FLIP-TESTING AND PACKING

Immediately upon removal from the oven, the tin cans, with loosely clinched lids, are hermetically sealed by an automatic can-sealing ma-

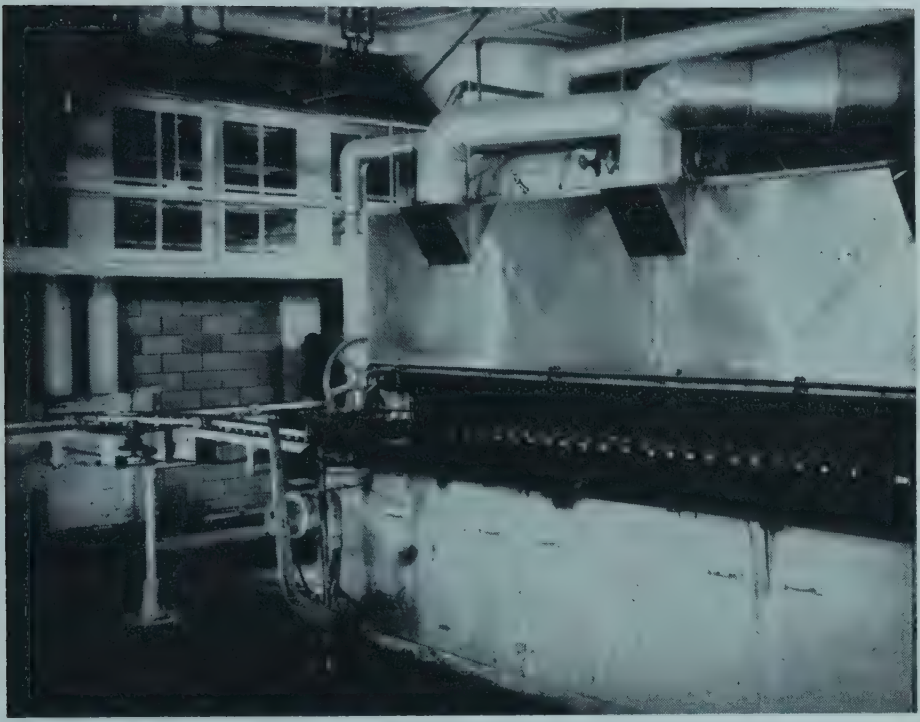
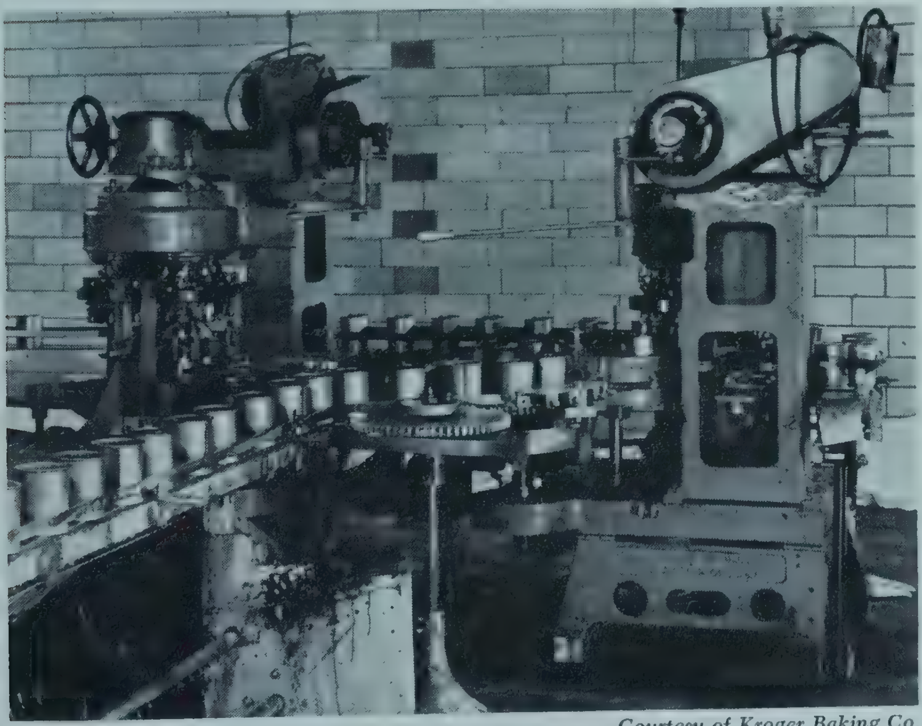
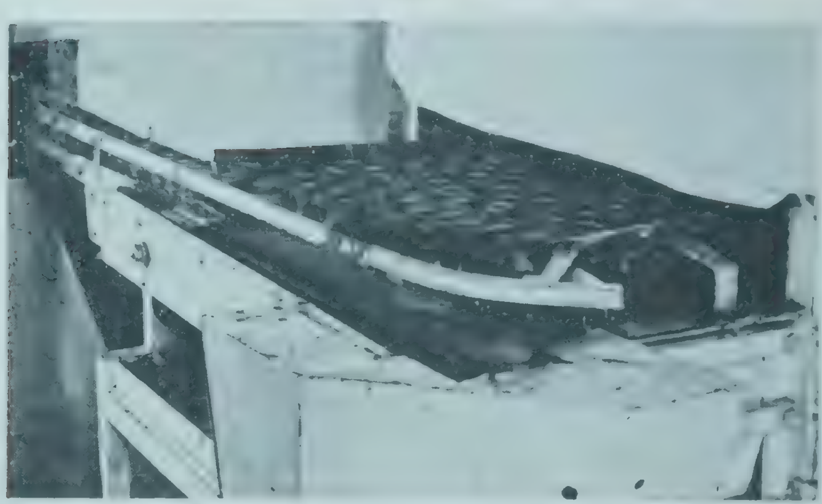


Fig. 136. Canned Baked Products Being Loaded into the Oven



Courtesy of Kroger Baking Co.

Fig. 137. Sealing the Lids on Cans of Baked Products Immediately After Removing Them from the Oven



Courtesy of Kroger Baking Co.

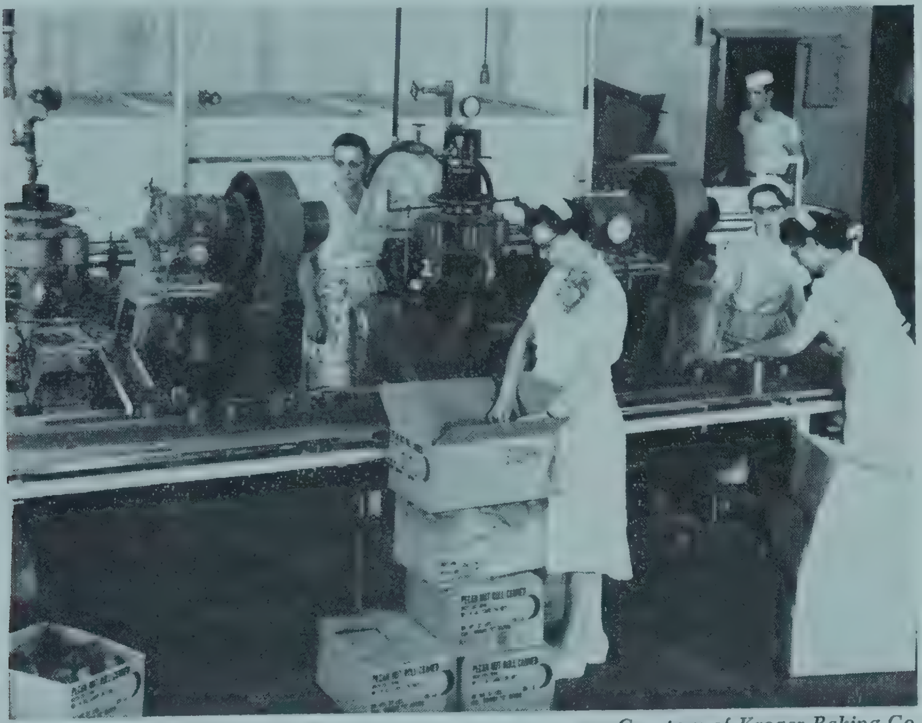
FIG. 138. CANNED BAKED PRODUCTS ENTERING WATER SPRAY COOLER IMMEDIATELY FOLLOWING CAN SEALING

chine (Fig. 137). As the sealed can and its contents cool, the steam atmosphere within the can condenses, creating a natural, high vacuum. A high internal vacuum of not less than 25 inches of mercury is necessary to preserve natural flavors and to prevent can corrosion during storage. In order to achieve this high internal vacuum, can sealing must be accomplished within 60 seconds after removal of the can from the oven. Thus, removal of cans from the oven must be carefully coordinated with can sealing.

Following this sealing operation, the canned baked products are rapidly cooled. Unless cooling is accomplished quickly, the color and flavor of the product in the can is impaired by "auto-baking." Rapid cooling may be accomplished in several ways, namely: (1) exposure (on rack) to fan-driven, rapidly moving air streams, (2) passage through a water spray tunnel, as shown in Fig. 138, or (3) immersion in running cold water.

To make certain that the can is perfectly sealed and possesses a high internal vacuum, the cooled can is run through an additional automatic machine known as a "flip-tester" (Fig. 139) which determines the presence or absence of vacuum within the can in the following manner. One end of the can (usually the top end) is placed under a close-fitting, rubber-seated bell. A 27- or 28-inch vacuum is applied within the bell above the can end by means of a vacuum pump. When the vacuum within the bell exceeds the vacuum within the can by 5 or 6 inches, the can lid bulges outward like the head of a drum producing an audible "flip." This outward bulging of the can lid activates a mechanism which rejects this can from the moving line. Cans possessing little or no vacuum are rejected as "mis-seals" or "leakers." The lids on cans having internal vacuums in excess of 20 inches, of course, will not bulge outward and will, therefore, pass through the machine as acceptable. After "flip-testing" the clean dry cans are packed into containers for shipment.

Tin cans used for manufacturing canned baked products may be purchased from any of several can manufacturers. The tin cans should be enamelled internally with a lacquer known among can manufacturers as "C" enamel to eliminate can corrosion after baking. Tin cans may also be enamelled or lithographed externally. The darker the color of the can exterior the better will be its baking characteristics because dark colors absorb heat while light colors reflect heat.



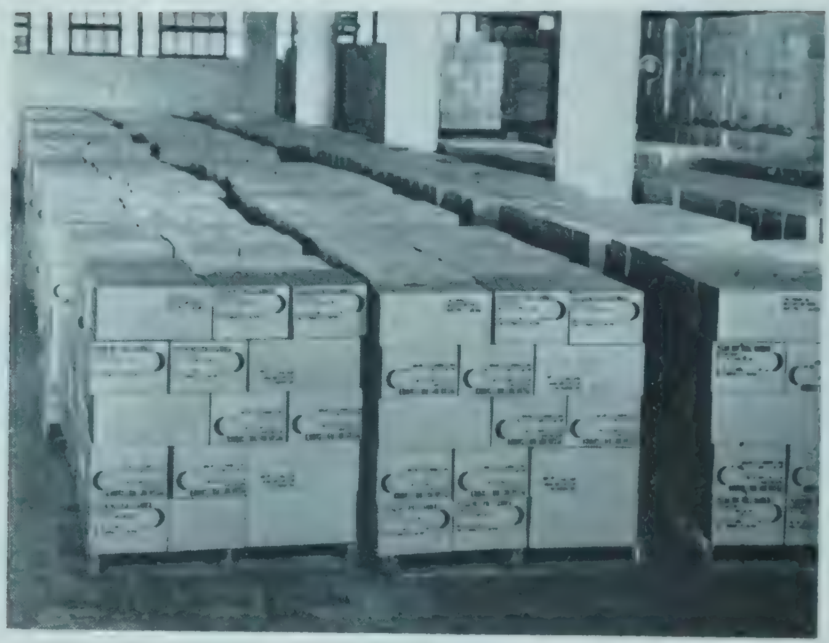
Courtesy of Kroger Baking Co.

FIG. 139. CANNED BAKED PRODUCTS PASSING THROUGH "FLIP-TESTER" PRIOR TO BEING PACKED INTO CARTONS

Can clinching, can sealing and "flip-testing" equipment is fully automatic and operates at production rates of from 60 to 180 cans per minute. Even greater production rates can be obtained by installing supplementary canning machinery. These can-processing machines are obtainable from can manufacturers on a rental basis or by purchase at reasonable cost.

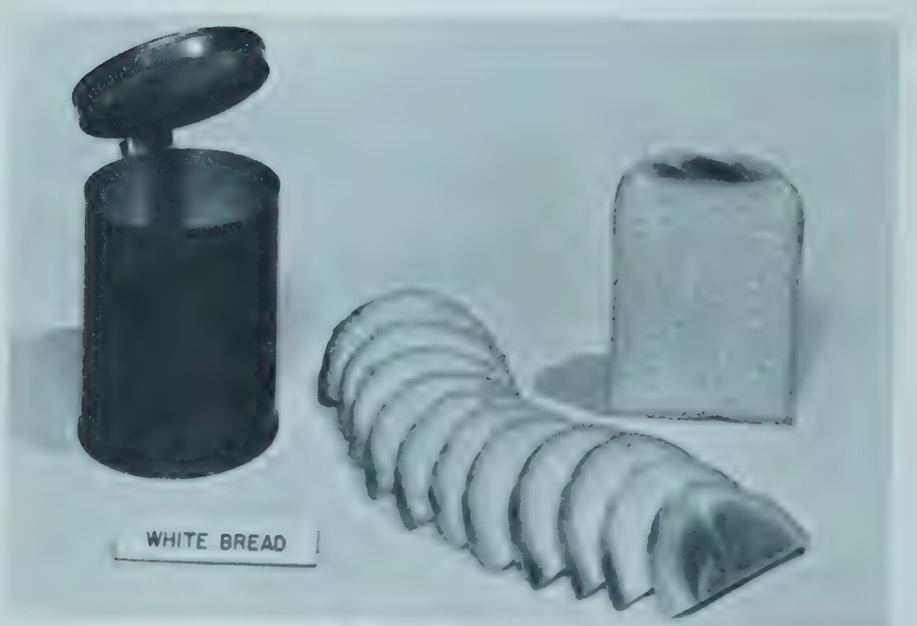
FORMULATIONS AND PROCESSING

Possible formulations and processing steps for individual canned baked products are exemplified by bakery foods included in Military Rations:



Courtesy of Kroger Baking Co.

FIG. 140. CANNED BAKED PRODUCTS READY FOR SHIPMENT



Courtesy of Quartermaster Food and Container Institut

FIG. 141. CANNED WHITE BREAD OF THE TYPE USED FOR ARMED FORCES' RATIONS

(1) canned white bread, (2) canned poundcake, (3) canned fruitcake, and (4) canned pecan roll described as follows:

Canned White Bread

The military canned white bread (see Fig. 141), in four can sizes, is defined in explicit detail in the current revision of Military Specification MIL-B-1070, "Bread, Canned."

Ingredients and Formula.—Manufacture of the military canned white bread utilizes a bleached and matured, enriched hard winter wheat flour, compressed yeast (or equivalent of active dry yeast), salt, and sugar (cane, beet or corn). Less common bakery ingredients in the formulation are buttermilk solids and edible lactic acid (to increase acidity and improve keeping properties of the canned bread), inactive dry yeast (for added vitamin fortification), and a special rancidity-resistant shortening known as "100-hour shortening." A large percentage of shortening is employed in the formulation to provide a high calorie content in the canned bread. Absorption in the dough is held at 50 per cent or less to facilitate achieving a finished baked bread moisture content of 35 per cent or less to assure adequate keeping properties. The formula utilized in the military canned bread is listed as follows:

Ingredients	*Parts by Weight*
Hard wheat flour enriched	100.00
Water, not more than	50.00
Compressed yeast[1]	2.00
Salt	1.75
Sugar (cane, beet or corn)	8.00
Shortening	12.00
Buttermilk solids	2.00
Edible lactic acid (60 per cent)	0.30
Inactive dry yeast	1.50

Dough Processing.—Military canned bread is made by the 100 per cent sponge process. All of the sifted flour, water and yeast are combined into a sponge using a moderate amount of mixing in the customary manner. Temperature of the sponge at completion of mixing is held between 78° to 82°F. The sponge is fermented for not less than three hours in an air-conditioned fermentation room or in a "cabinet" fermentation box. Prior to combining with the sponge, the balance of the canned bread ingredients (sugar, shortening, buttermilk solids, salt and lactic acid) are mixed into a creamed mass to achieve even distribution of the buttermilk solids in the dough. The fermented sponge is then placed in the mixer, combined with the creamed mass, and mixed at high speed until the gluten is fully developed. Temperature of the resulting dough is controlled by use of ice water or brine in the cooling jacket of the mixer so that the dough, when dumped from the mixer, does not exceed 86° F.

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[1] Or equivalent active dry yeast.

Dividing and Canning.—Without floor time, the canned bread dough is then divided into dough pieces of the proper weight. The standard commercial dough divider capable of scaling uniform 10-ounce dough pieces is satisfactory for the 401 x 411 can size. For the smaller can sizes, an automatic bun divider is required. Alternatively, two five-ounce pieces, scaled on the bun divider, may be used for the 401 x 411 can size. Can size, scaling weight, and yield of baked bread are summarized in the following table:

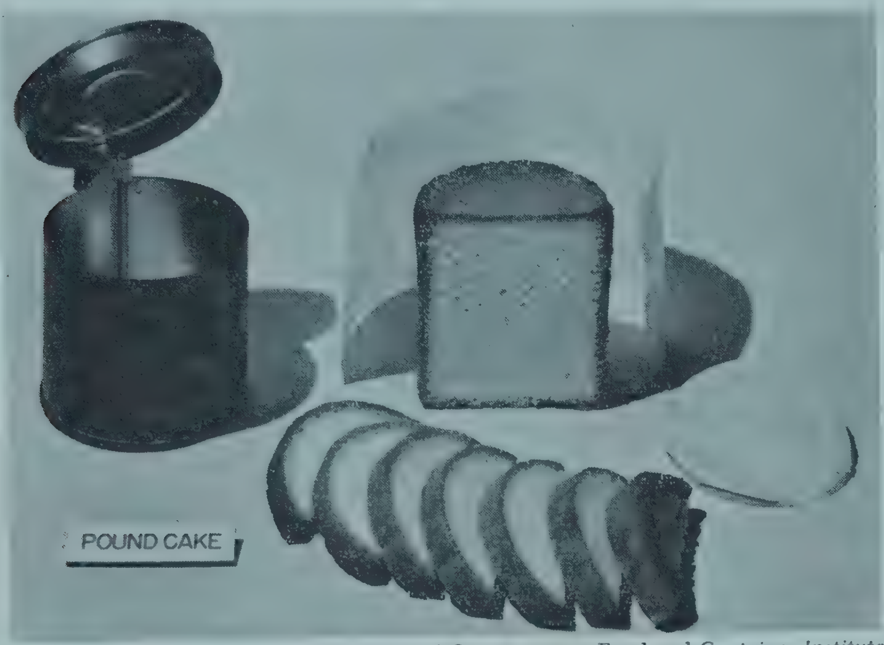
Can Size	Scaling Weight, Ounces	Minimum Baked Contents, Ounces
401 x 411	10.0	9.50
300 x 407	5.0	4.50
300 x 308	4.0	3.75
300 x 200	2.0	1.75

After dividing, the dough pieces may be rounded in the standard rounder; however, this operation is not required. Prior to placing in the tin can, the dough pieces are covered by a film of shortening (instead of greasing the cans). This may be accomplished by rotating the dough pieces over a short moving belt, coated with melted shortening, under a wide, flexible drag-chain. The dough pieces then are deposited by hand into clean, dry, empty tin cans and the lids are attached in a clinching machine. In this operation, the lids are loosely attached by a single or "first-roll" operation. By code markings imprinted on the can lid, the batch number and date of baking are marked on each can.

Proofing and Baking.—The cans of bread then are proofed. In order to determine the proper proof, the lids of several control cans for each dough batch are not clinched but merely placed on the cans so that they may be removed for observation. When the proofed dough occupies approximately 50 to 60 per cent of the total can volume, the cans are loaded into the oven for baking. Proofing must be carefully controlled since under-proofing will yield a loaf of bread which does not fill the can completely and over-proofing results in a compression streak in the baked loaf. When properly proofed, the canned bread is loaded into the oven for baking. The cans are evenly spaced in the oven (minimum distance between cans approximately 1½ inches). The canned bread is baked at 425° F. for 15 to 35 minutes, depending upon can size. Procedures on can sealing, cooling, flip-testing and packing are previously described.

Canned Poundcake

The military canned poundcake (see Fig. 142), in four can sizes, is defined in explicit detail in the current revision of Military Specification MIL-P-3234, "Pound Cake, Canned."



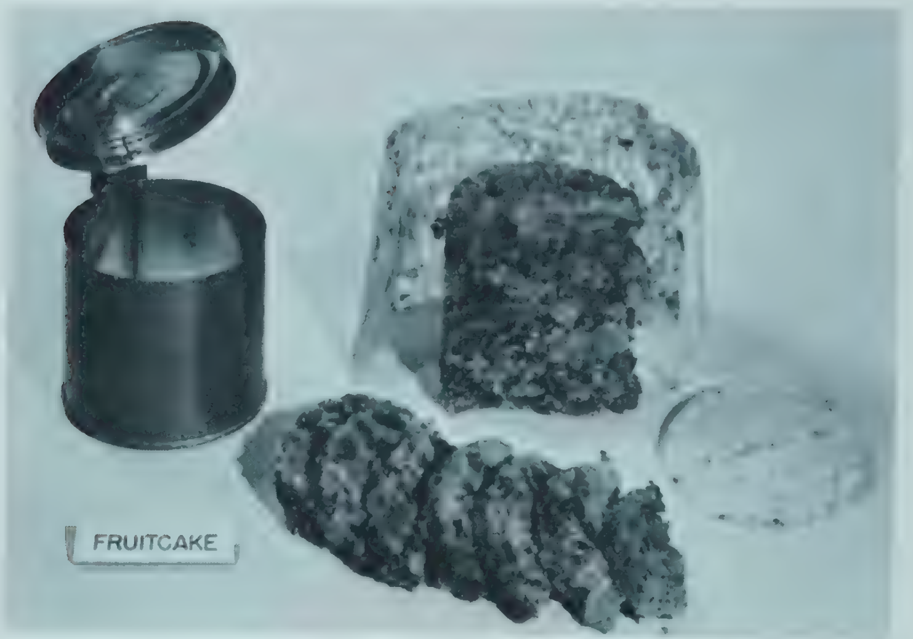
Courtesy of Quartermaster Food and Container Institute

FIG. 142. CANNED POUND CAKE

Ingredients and Formula.—Ingredients employed in the manufacture of canned poundcake are all common to cake manufacture and include a bleached soft wheat flour, granulated sugar, shortening (rancidity resistant 100-hour type), whole eggs, egg yolks, salt, and vanilla flavoring. The formula utilized in the military canned poundcake is listed as follows:

Ingredients	*Parts by Weight*
Soft wheat flour	25.00
Shortening	25.00
Whole eggs	12.50
Egg yolks	12.50
Granulated sugar	25.00
Salt	(as required)
Vanilla flavoring	(as required)

Batter Processing.—The poundcake batter is prepared in the normal manner by creaming the shortening with the sugar or flour and then gradually adding the balance of the other ingredients until a smooth homogeneous mixture is obtained.



Courtesy of Quartermaster Food and Container Institute

Fig. 143. Canned Baked Fruitcake

A retorted (steamed) fruitcake of somewhat similar composition is also used in Armed Forces' rations.

Depositing, Clinching and Baking.—Prior to filling with batter, the cans are lined with vegetable parchment paper utilizing a die-cut paper disc for the can bottom and a die-cut strip for the can walls. For the 300 x 200 can, a fluted paper cup made from vegetable parchment paper may be used. Cake batter is then deposited into the cans utilizing a can filler or a cake depositor modified to feed tin cans automatically. Can size, scaling weight and yield of baked cake are summarized in the following table:

Can Size	Scaling Weight, Ounces	Minimum Baked Contents, Ounces
401 x 411	12.5	11.50
307 x 409	8.5	7.75
300 x 308	5.0	4.50
300 x 200	2.5	2.20

After filling, the lids are loosely attached to the cans in a clinching machine by a single or "first-roll" operation. By code markings imprinted on the can lid, the batch number and date of baking are marked on each can. The cans are then loaded into the oven for baking at 350° F. for 15 to 40 minutes, depending upon can size. The cans are evenly spaced in the oven (minimum distance between cans approximately 1½ inches).

Procedures on can sealing, cooling, flip-testing and packing are those previously described.

Canned Fruitcake

The military canned fruitcake (see Fig. 143), in four can sizes, is defined in explicit detail in the current revision of Military Specification MIL-F-3232 "Fruitcake, Fresh and Fruitcake, Canned."

Ingredients and Formula.—Ingredients employed in the manufacture of canned fruitcake are all common to fruitcake manufacture and include bleached hard wheat flour, shortening (rancidity resistant 100-hour type), whole eggs, granulated sugar, salt, vanilla flavoring, water, bleached seedless raisins, unbleached seedless raisins, diced glacé cherries, diced glacé pineapple, diced glacé citron, diced glacé orange peel, diced glacé lemon peel and pecan pieces. The formulas used for the cake batter and fruit blend are listed as follows:

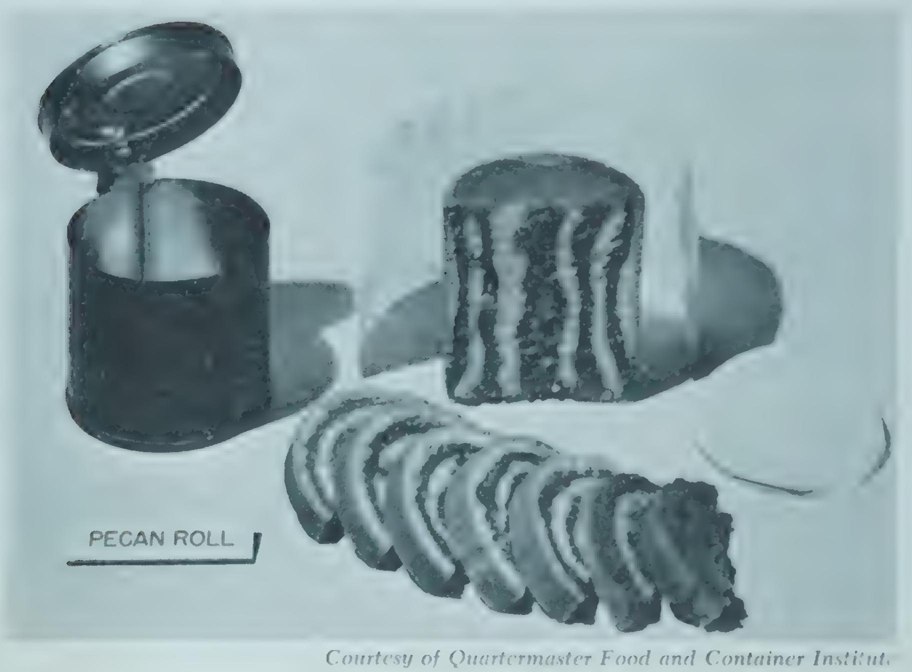
Cake Batter

Ingredients	*Parts by Weight*
Bleached hard wheat flour	24.00
Shortening	18.00
Whole eggs	20.00
Granulated sugar	27.00
Salt	0.75
Vanilla flavoring (approximately)	0.25
Water (approximately)	10.00
Total	100.00

Fruit Blend

Ingredients	*Parts by Weight*
Raisins, seedless, unbleached	12.50
Raisins, seedless, bleached	12.50
Cherries, diced	25.00
Pineapple, diced	15.00
Citron, diced	7.00
Orange peel, diced	6.00
Lemon peel, diced	2.00
Pecan pieces	20.00
Total	100.00

Fruitcake Batter Preparation.—The batter for the fruitcake is prepared by creaming the shortening with the sugar or flour and then gradually adding the balance of the other ingredients during mixing until a smooth homogeneous mixture is obtained.



Courtesy of Quartermaster Food and Container Institute

Fig. 144. Canned Pecan Roll

Before blending with the cake batter, the blanched raisins and drained glacé fruits are blended thoroughly with the balance of the fruit-and-nut blend. Thirty-five parts of cake batter and 65 parts of the fruit-and-nut blend are then mixed thoroughly to yield the finished fruitcake mix.

Prior to filling with fruitcake mix, the cans are lined with vegetable parchment paper utilizing a die-cut paper disc for the can bottom and a die-cut strip for the can walls. For the 200 x 300 can, a fluted paper cup made from vegetable parchment paper may be used. The fruitcake mix is then deposited into the cans utilizing a can filler or a cake depositer modified to feed tin cans automatically. Can size, scaling weights and yield of baked cake are summarized in the following table:

Can Size	Scaling Weight, Ounces	Minimum Baked Contents, Ounces
401 x 411	24.50	24.0
300 x 407	12.50	12.0
300 x 308	9.50	9.0
300 x 200	5.25	5.0

After filling, the lids are attached loosely to the cans in a clinching machine by a single or "first-roll" operation. By code markings imprinted on the can lid, the batch number and date of baking are marked on each can. The cans are then loaded into the oven for baking at 300° to 325° F for 30 minutes to 2 hours, depending upon can size. During baking, the canned fruitcake should be spaced evenly in the oven (minimum distance between cans approximately 1½ inches). Procedures on can sealing, cooling, flip-testing and packing are those previously described.

Canned Pecan Roll

The military canned pecan roll (see Fig. 144), in four can sizes, is defined in explicit detail in the current revision of Military Specification MIL-P-35000, "Pecan Roll, Canned."

Ingredients and Formulas.—Ingredients employed in the manufacture of canned pecan roll are all common to yeast leavened pastry baking and include bleached and matured hard wheat flour, non-fat milk solids, shortening (rancidity resistant 100-hour type), water, compressed yeast (or active dry yeast), granulated sugar, egg yolks, salt, honey, ground cinnamon, pure vanilla extract and midget pecan pieces. The pecan roll is composed of two distinct portions; i.e., the dough and the filling. The formulas for each are listed as follows:

Dough Formula

Ingredients	*Parts by Weight*
Hard wheat flour	46.00
Non-fat milk solids	2.00
Water	15.50
Shortening	16.00
Compressed yeast[1]	2.00
Granulated sugar	10.00
Egg yolks	8.00
Salt	0.50
Total	100.00

Filling Formula

Ingredients	*Parts by Weight*
Granulated sugar	23.00
Honey	24.00
Shortening	13.00
Ground cinnamon	2.00
Salt	1.00
Pure vanilla extract[2]	0.50
Hard wheat flour	24.50
Midget pecan pieces	12.00
Total	100.00

Processing and "Make-Up."—The pecan roll dough is prepared by a straight dough method. The temperature of the dough is controlled so

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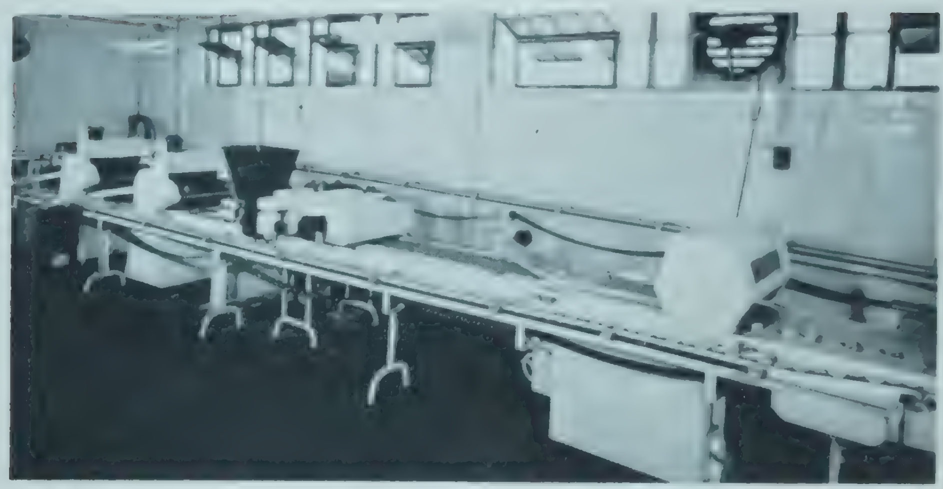
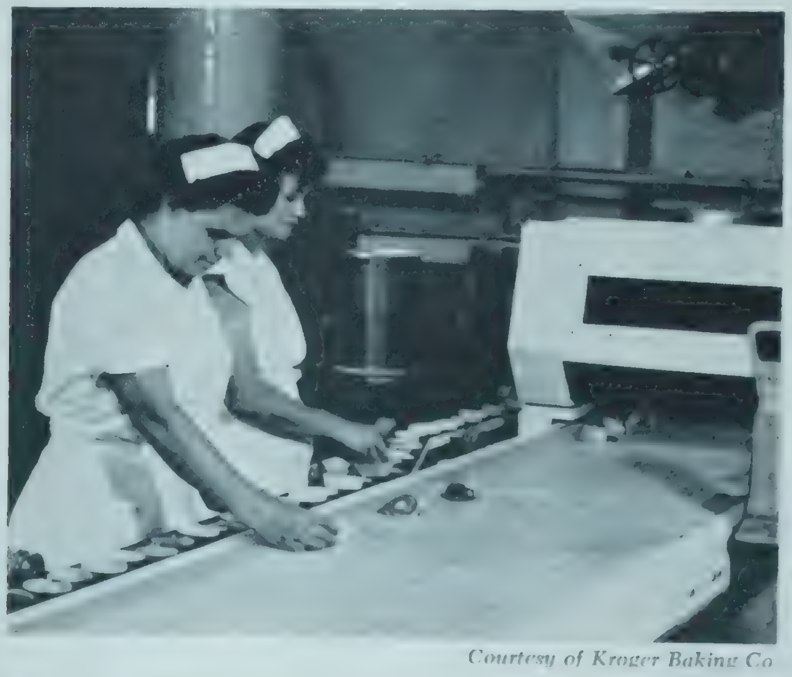
[1] Or equivalent quantity of active dry yeast.

[2] Single strength.



Courtesy of Kroger Baking Co.

FIG. 145. MECHANICAL BENCH EMPLOYED IN PREPARING CANNED PECAN ROLL



Courtesy of Kroger Baking Co

FIG. 146. PECAN ROLL DOUGH BEING CUT BY A "GUILLOTINE CUTTER PRIOR TO BEING PLACED INTO PAPER-LINED CANS

that it does not exceed 82° F. The dough is given only sufficient fermentation time to relax the flour gluten and achieve optimum machinability.

The pecan roll filling is prepared by blending all ingredients on slow speed in a mixer until a uniform creamed mass is obtained.

The pecan roll dough is continuously sheeted on a mechanical bench (Fig. 145) so that the dough sheet is not less than ten inches wide, and a nine square inch piece does not weigh more than one ounce. The filling then is continuously sheeted onto the pecan roll dough and is synchronized so as to yield equal weights of dough and filling over any given surface area. The resulting sheeted dough and filling then is rolled mechanically and continuously in a spiral (as in a cinnamon bun) so that the roll has six distinct layers of dough and five layers of filling when cut at a right angle to the length of the roll. Cutting to the proper size and weight is accomplished mechanically utilizing a "guillotine" cutter, shown in Fig. 146.

Depositing, Clinching and Baking.—Prior to filling, the tin cans are lined with silicone-treated vegetable parchment paper utilizing a die-cut disc for the can bottom and a die-cut strip for the can walls. The raw pecan roll is then placed in the tin can so that the dough strip is parallel to the can wall. Can size, scaling weight, and yield of baked pecan roll are summarized in the following table:

Can Size	Scaling Weight, Ounces	Minimum Baked Contents, Ounces
401 x 411	20.50	19.50
300 x 407	10.50	10.00
300 x 308	8.25	8.00
300 x 200	4.50	4.25

After filling, the lids are attached loosely to the cans in a clinching machine by a single or "first-roll" operation. By code marking imprinted on the can lid, the batch number and date of baking is marked on each can. The cans are then loaded into the oven for baking at 400°F. for 20 to 60 minutes, depending upon can size. During baking, the canned pecan roll should be spaced evenly in the oven (minimum distance between cans approximately 1$^1/_2$ inches). Procedures on can sealing, cooling, flip-testing and packing are those previously described.

BACTERIOLOGICAL ASPECTS OF CANNED BAKED PRODUCTS

Undoubtedly, the most difficult problem in the development of canned baked products was solution of the bacteriological or food poisoning hazards in the finished baked product. In canned cakes (both poundcake and fruitcake) and in the pecan roll the high sugar content normally inhibits growth of bacteria. Most authorities regard soluble solids content above 72 per cent to be completely inhibitory. The military canned cakes and pecan roll reach these safe limits. In canned bread, however, such is not the case.

One particular heat resistant species of bacteria, *Clostridium botulinum*, is potentially extremely toxic in canned bread, as in many other foods. These bacteria are frequently found in soil and airborne dust and therefore, may be present in several of the ingredients used in the manufacture of canned bread. The bacteria or spore, in itself, is harmless, however, when conditions are favorable for the germination of this spore, a highly poisonous toxin is produced by the growing bacteria. Consumption of a food containing this lethal toxin by a human or other warm-blooded animal produces the illness botulism, which can, and usually does, result in death.

Two solutions to this toxicity problem are potentially feasible: (1) process the canned bread with sufficient heat to destroy the bacteria and its spores, as is standard practice in most canned foods (canned meats, for example), or (2) modify the formula and conditions within the canned bread so that the bacteria or spore, if present, cannot germinate and produce toxin (modify the pH, for example).

While canned bread is baked in a 400° to 450° F. oven, the temperature within the loaf never exceeds 210° F. during baking. Since a temperature of 250° F. for approximately three minutes is required to destroy the *botulinum* spores, baking cannot accomplish sterilization. Research demonstrated that heat processing of canned bread in a retort (under high pressure, high temperature steam) to sterilize the baked bread produced objectionable discoloration and off-flavors rendering the product unacceptable.

The second alternative proved more promising. Bacteriological research sponsored by the Quartermaster Corps and reported by Kadavy and Dack (1951) and Wagenaar and Dack (1954) demonstrated that *Cl. botulinum* spores in canned bread of moisture contents of 35.0 per cent or less, regardless of pH, would not germinate and produce toxin. In addition, this research demonstrated that *Cl. Botulinum* spores in canned bread of pH 4.8 or less, regardless of moisture content, would not germinate and produce toxin. Consequently, the military canned bread product is manufactured in such a manner as to yield a finished product containing less than 35.0 per cent moisture and a pH value of 4.8 or less, thereby providing bacteriological safety.

To insure bacteriological safety during storage it is necessary that the bacteriological inhibiting properties of the finished product (sugar solids contents in canned poundcake, fruitcake and pecan roll and the moisture content and pH value in canned bread) do not change. Imperfectly sealed tin cans would afford opportunity for change in these critical factors. To preclude this hazard all canned baked products are subjected to the "flip-testing" operation to screen out imperfectly sealed tin cans.

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CHAPTER 20

Donald K. Tressler

Freezing of Bakery Products

INTRODUCTION

Although the commercial freezing of bread, cake and other baked products has been practiced less than ten years, the freezing of bread by farmers, hunters and trappers has long been a common practice in winter in cold climates. Some of the farmers in the isolated sections of the Gaspe Peninsula still use big ovens, often located out-of-doors, to make a supply of bread large enough to feed their families for several weeks, and then keep the bread in an unheated room where it soon freezes, and once frozen, retains its freshness for many weeks.

At present two bakers, who produce bread of the "homemade type," freeze bread on a large scale. One of these bakeries freezes only the bread which is to be shipped a considerable distance; on arrival at destination the bread is thawed before sale. The frozen bread produced by the other company is not thawed before sale at retail. Other bakeries are experimenting with bread freezing, some of which is carried on on a pilot plant scale.

Cakes, of various kinds, shortcakes, waffles, and pancakes are also frozen on an important scale and marketed from frozen food cabinets. Unbaked doughs and batters of many kinds are also frozen.

Of particular interest is the new system of making the doughs and batters in a central plant, freezing the goods ready for baking, transporting them to a chain of retail stores, where they are held until needed for sale, then baked and sold very shortly thereafter (Anon. 1959A). Items marketed in this way include cheesecakes, poundcakes, and marble cakes, cream pies, miniature Danish pastries, coffee rings, cheesecake strips, apple turnovers, and individual onion rolls.

Freezing is an almost ideal method of preserving nearly all baked products. Although a few cakes and specially prepared bread of low pH can be preserved by canning (see Chap. 19), canning is not likely to have wide application for the preservation of baked goods. Bread, if frozen rapidly and maintained at 0 F. or below, retains its freshness for many months (Tressler and Evers 1957). Some kinds of frozen cakes retain their freshness almost perfectly for long periods, others have a relatively short storage life.

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BREAD

Importance of Freezing

Because of the relatively short storage life of freshly baked bread, any method of preservation which makes possible the holding of bread for long periods is of great interest. The magazine *Baking Industry* conducted a survey (Anon. 1954B) which indicated that a wholesaler with 22 routes, with 51 daily stops on each route, had an annual return in 1953 of stale bread worth more than $64,000. The average gross profit in that year of the wholesalers surveyed was $61,500. It is evident, therefore, that if the freezing of bread will eliminate the losses resulting from the return of stale bread, the baker's profit will be materially greater than it now is.

Freezing of bread would help the baker to have regular production schedules at normal working hours, and consequently simplify his labor problems. It may also be possible for the baker who freezes his bread to furnish his customers with a product having a more uniformly high quality than is now the case.

Influence of Temperature on Rate of Staling

Cool bread (unfrozen) becomes stale in much less time than warm bread. Using only physical characteristics as criteria Katz (1928, 1934) found that at 140°F. bread would stay "fresh" indefinitely (flavor deteriorates rapidly at this temperature); and, further, that at ordinary room temperatures the rate of staling was most rapid during the first twelve hours. His observations indicated that the maximum rate of staling occurred at temperatures of +27°F. to +29°F., and that the rate decreases as the temperature is raised or lowered.

Many research workers have demonstrated that, although bread stales very rapidly at its freezing point, if it is stored at 0°F. and below the rate of staling is very slow. At —30°F., the bread is still palatable after approximately one year's storage (Onnes 1937; Cathcart and Luber 1939; Cathcart 1941; Pence *et al.* 1955A, B, and C).

Cathcart and Luber (1939) drew the following conclusions from a careful comprehensive detailed study of changes in commercially baked bread held in a commercial freezer at +12°, —8°, and —31°F.:

> "According to swelling power tests, bread staled rapidly at temperatures as low as —8°F. This test showed that it was about half stale when placed in the freezer (eight hours out of the oven) and nearly completely stale after 24 hrs. in the freezer. At about —31°F., the bread was kept in its original fresh condition for a period of about four days and required 8 to 10 days to become nearly stale, according to the swelling power test. When the tests were con-

tinued for 60 to 70 days, a refreshening of the bread was observed, the sediment returned to values in the neighborhood of those for unfrozen bread eight hours out of the oven.

"According to aroma and taste tests, bread frozen at −8° F. remained good for 20 days and salable for approximately 40 days. At −31° F. it has a much better keeping quality and remained in a saleable condition for much longer periods of time.

"Although the change in the starch, which the swelling power test measures, is important, it does not tell the whole story about staling.

"The development of an off-aroma was the limiting factor for the time the bread could be kept saleable by freezing at the temperature used.

"At −8° F., carbon dioxide in the freezing chamber did not improve the keeping qualities.

"When bread frozen at −8° F. was removed from the freezer, it staled at about the same rate as ordinary bread. . . .

"Although bread does not keep indefinitely at the temperatures employed, freezing offers an excellent means of keeping commercial bread in a saleable condition for 40 days or longer. It must be remembered that all frozen products deteriorate slowly during storage, when comparing the practicability of freezing bread with other food products."

More recently, Pence *et al.* (1955C) studied the effect of storage temperature on firmness increases in frozen bread and reported that the firmness increases fairly rapidly at 15°, more slowly at +10°, and very little or not at all at 0° F. or below. Their data are presented below:

Storage Temperature, °F.	Days	Average Increases in Firmness, G./4 mm. Compression
15	3	27
10	24	14
0	24	0
−10	24	0

TABLE 75

EFFECT OF AGE OF BREAD AT TIME OF FREEZING ON FIRMNESS AND TASTE-PANEL EVALUATION OF FRESHNESS AFTER DEFROSTING[1]

Age at Time of Freezing Hours	Firmness, G./4 mm. Compression	Mean Rank by Taste Panel[2]
	Freshly Defrosted	
4	92	1.3
11	109	1.8
34	131	2.9
	48 Hours After Defrosting	
4	172	1.2
11	183	2.3
34	201	2.5

[1] From Pence *et al.* (1955C).

[2] Judges were asked to rate samples in order of freshness so that the freshest sample [illegible] of 1, the next freshest 2, and so on. Comparisons in rank cannot be made between results obtained at separate testing times.

Since staling takes place most rapidly during the first few hours after baking, bread should be frozen as soon as possible after it comes from the oven. This was shown by Pence *et al.* (1955C) in a study in which they used a taste panel and determined the firmness of bread frozen 4, 11, and 34 hours after baking. Their results are shown in Table 75.

These workers also studied the effect of variations in the storage temperature on the firmness of bread frozen at —20°F. and noted that, when the temperature was fluctuated between 0° and 20°F. (on a 24-hour cycle), the bread soon lost its compressibility (Table 76).

TABLE 76

EFFECT OF A VARIABLE STORAGE TEMPERATURE ON FIRMNESS IN FROZEN BREAD (TEMPERATURE FLUCTUATED BETWEEN 0° AND 20°F. ON A 24-HOUR CYCLE[1])

Days in Storage	Firmness, G./4 mm. Compression
0	94
7	123
14	131
28	165

[1] From Pence *et al.* (1955C).

Pence *et al.* (1955C) also compared the firmness of the crumb of bread thawed at different rates. Their results follows:

Defrosting Time, Hrs.	Average Increase in Firmness, G./4 mm. Compression
2.3	13
5.5	32
10.8	31

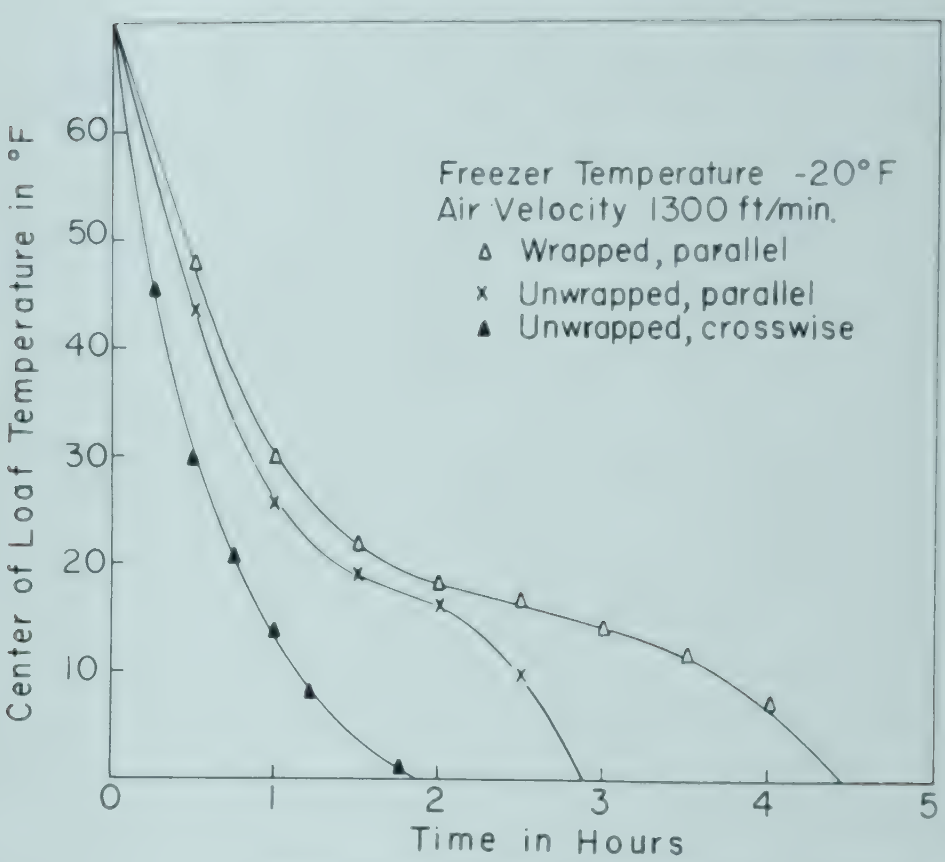
These data indicate the value of rapid thawing.

These researchers also considered the effect of refreezing after thawing. They used unsliced, round-top loaves of bread which had been frozen at —20°F. in about 90 minutes. The bread was held in a freezer at 0°F. overnight, removed to room temperature to thaw for five hours, then refrozen at 0°F. Their data are presented in Table 77.

TABLE 77

EFFECT OF REPEATED FREEZING AND THAWING ON THE FIRMNESS OF BREAD USING G/4 MM. COMPRESSION

Number of Cycles	Firmness	Difference
0 (Fresh)	57	..
1	85	28
2	102	17
3	114	12



Courtesy of Western Utilization Research Branch, U.S. Dept. Agr.

FIG. 147. RATE OF FREEZING OF WRAPPED AND UNWRAPPED BREAD −20°F. PLACED PARALLEL TO AIR FLOW, AND UNWRAPPED BREAD PLACED CROSSWISE TO AIR FLOW

If the frozen bread is thawed and held at ordinary room temperatures it retains its freshness about as long as fresh bread which has not been frozen (Pence and Standridge 1955; Anderson 1954).

Packaging

Work by Cathcart (1941) indicated that the packaging of freshly baked bread in hermetically sealed cans prior to freezing greatly increased the length of time that the frozen product can be kept without marked staling. In fact, bread sealed in a normal atmosphere remained saleable in cold storage for approximately one year. That which was vacuum packed not only remained saleable, but was quite similar to freshly baked bread at the end of the year's storage.

Pence *et al.* (1955B) compared the rate of freezing of wrapped and unwrapped bread in an airblast freezer at −20 F. and observed that the unwrapped bread froze in much less time (Fig. 147). The unwrapped fresh bread loses little weight during freezing in an airblast. These workers reported that loaves of unwrapped bread placed in the freezer three hours after leaving the oven lost an average of only four grams (approximately 1/7 oz.) during freezing in a —20°F. airblast with 1200 ft. per min. velocity. However, they found that the loaves of unwrapped bread continued to lose moisture during storage at 0°F. at the rate of approximately two grams (1/14 oz.) moisture per day. They concluded that freshly baked bread can be safely frozen unwrapped, but a wrapper is necessary to prevent serious moisture losses during storage.

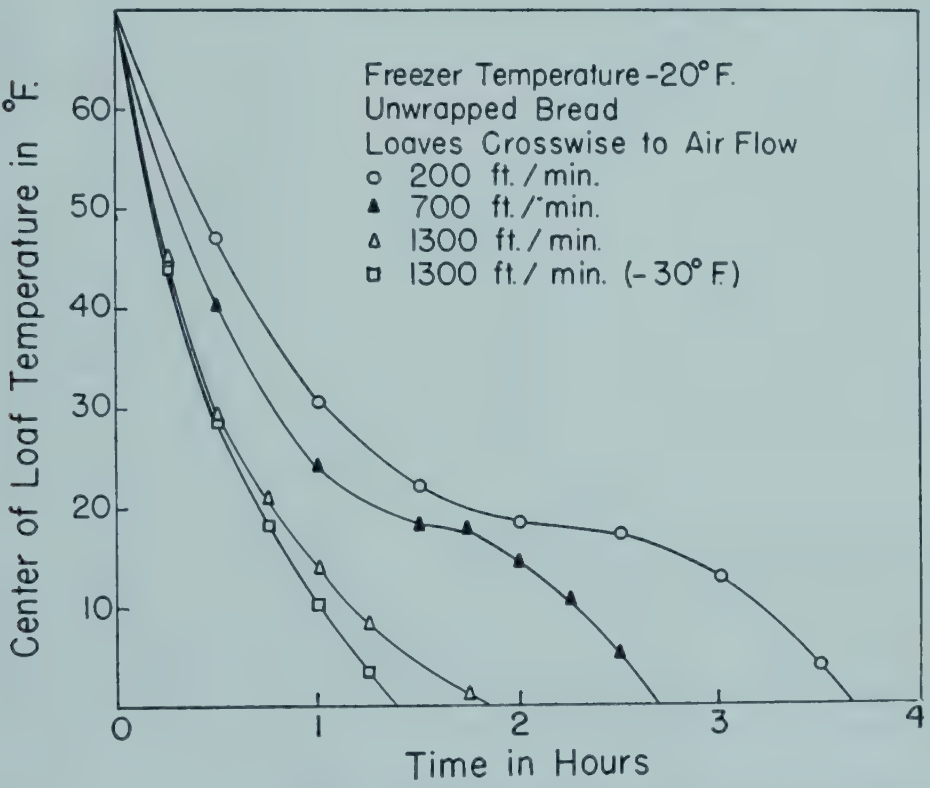


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FIG. 148. EFFECT OF AIR VELOCITY AT LOW TEMPERATURES ON RATE OF FREEZING OF UNWRAPPED BREAD

Despite the advantage gained by the more rapid freezing of the unwrapped bread, followed by prompt packaging of the frozen bread, most bread frozen commercially is wrapped before freezing.

Points to be taken into consideration in choosing a wrapper for bread to be frozen include the following: Bread shrinks about six per cent during freezing, so, if the bread is wrapped before freezing, the wrappers fit loosely. During defrosting moisture usually condenses on the wrapper. A desirable wrapper should be both sturdy and flexible to minimize wrinkling and cracking due to handling of the frozen or partially de-

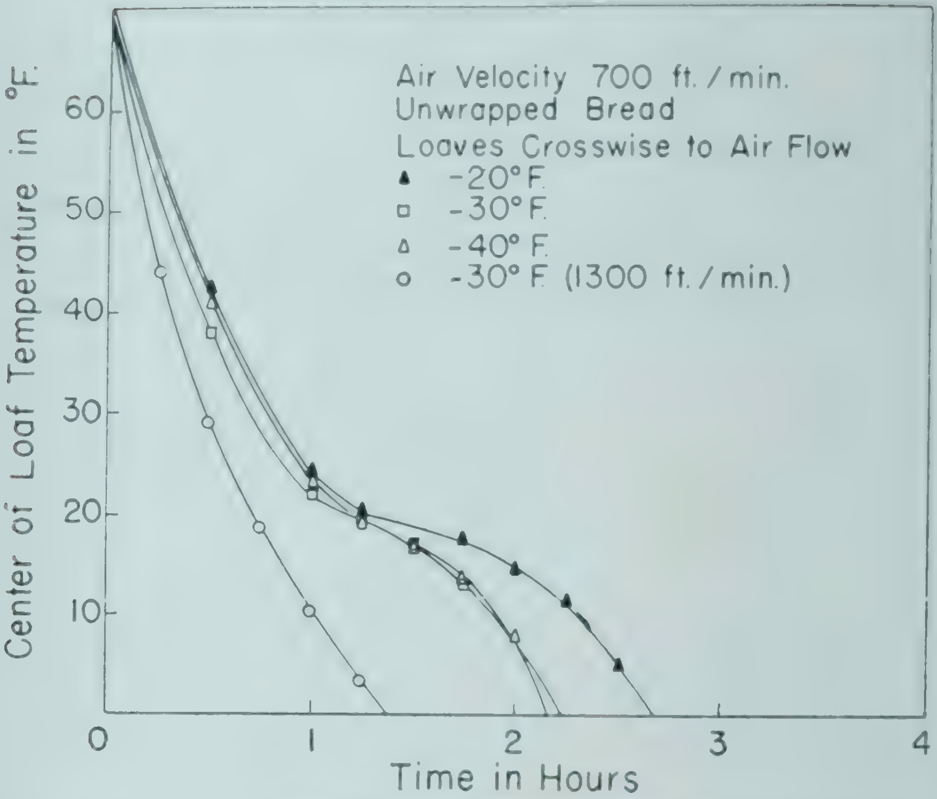

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FIG. 149. EFFECT OF AIR TEMPERATURE AT INTERMEDIATE AND HIGH AIR VELOCITIES ON RATE OF FREEZING OF UNWRAPPED BREAD

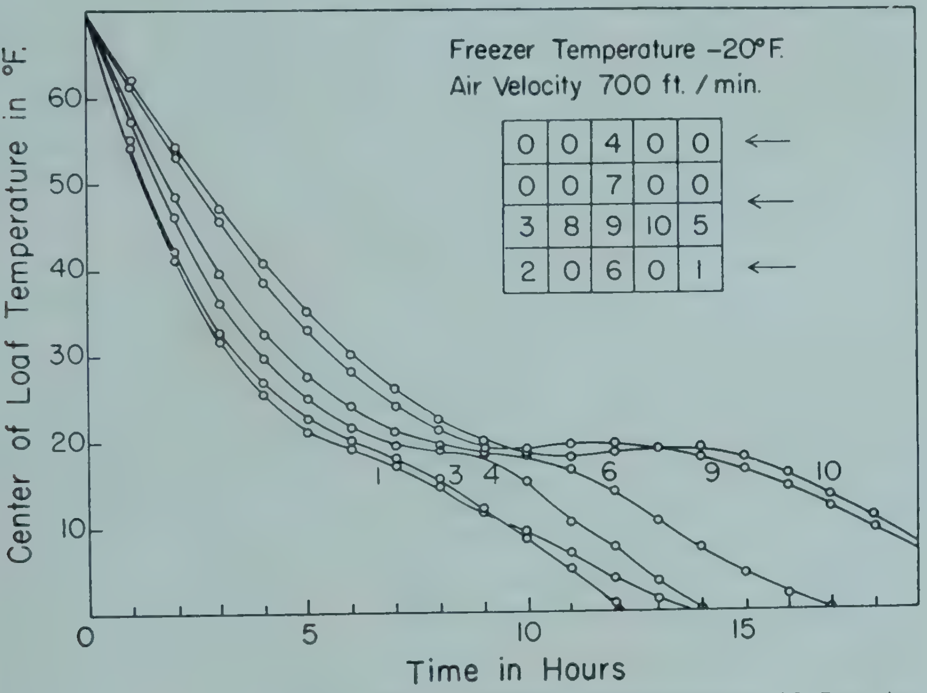
frosted bread. The wrapper should not absorb moisture and soften as otherwise it may be marked by the fingers during handling after defrosting. A heat-sealable wrapper which seals securely, and does not fall apart after moisture has condensed on it, is required.

Rate of Freezing Bread under Various Conditions

Pence *et al.* (1955A) at the Western Regional Research Laboratory have studied the effects of various factors on the rate of freezing. As a result of their studies of the effects of air velocity and temperature, freezing with and without a wrapper, and the position of the loaf in the airblast freezer, they concluded:

"Freezer temperature was found to be the variable with greatest effect on freezing rate of wrapped bread. With unwrapped bread, air velocity and position of the loaf in the airblast were factors of major importance. The most rapid method of freezing bread in the present experiments was by means of a high-velocity, low temperature blast of air at right angles to the long dimension of an unwrapped loaf. Individual loaves could be frozen in less than 30 min. by this method and no significant loss of moisture was incurred.

"The wrapper on a loaf of bread slowed the rate of freezing about as much as using a freezer temperature 10°F. higher. Wrapped bread packed in pasteboard cartons froze several times more slowly than individual loaves under similar freezer conditions."



Courtesy of Western Utilization Research Branch, U.S. Dept. Agr.

FIG. 150. RATE OF FREEZING OF WRAPPED BREAD, PACKED IN A PASTEBOARD DELIVERY CARTON, AT LOW TEMPERATURE AND INTERMEDIATE AIR VELOCITY

Numbers indicate position of test loaves in carton and order in which they froze. Arrows indicate direction of air flow.

The effect on the rate of freezing of unwrapped bread of varying the air velocity is shown in Fig. 148. The effect of varying the temperature from —20° to —40°F., and the velocity at —30°F. from 700 ft. to 1300 ft. per min., are shown in Fig. 149. They tried freezing wrapped bread in a fiberboard delivery carton in an air-blast at —20°F. (Fig. 150), and found it impossible to effect rapid freezing.

These workers also compared the freezing rates of unwrapped one-pound loaves of whole wheat, raisin and sour French bread. They found that whole wheat and white bread freeze at substantially the same rate despite a considerable difference in loaf density. Raisin bread freezes at a lower temperature than white bread, whereas French bread freezes at a higher temperature. Because of the shape of the loaf, French bread freezes more rapidly than the other breads studied.

In Fig. 147 (p. 538) are presented the curves obtained by Pence *et al.* (1955B) in studying the relative rate of freezing of wrapped and unwrapped bread when placed parallel to the airblast, and unwrapped bread placed parallel and crosswise to the direction of the air current. This work clearly indicated the advantages of placing the loaves crosswise to the airblast and the importance of freezing the bread before wrapping, if rapid freezing is to be obtained. Contrary to what might be expected, they found that unwrapped bread loses little weight during freezing in an airblast, but loses moisture during subsequent storage at 0°F. at the rate of approximately $^{1}/_{14}$ oz. per day.

The rate of freezing of wrapped bread in a York-Union continuous bread freezer is shown in Fig. 159 (p. 557).

Storage Life of Frozen Bread

As has previously been indicated, frozen bread becomes stale very slowly indeed. The lower the storage temperature the more slowly it becomes stale (p. 536). Early workers reported that bread, quick frozen immediately after baking, held one year at 0° F. was equivalent in freshness to bread held one day at 70° F. This is probably a slight exaggeration. In order to retain freshness as well as this, the storage temperature should be —20°F. or below.

Formation of White Rings in Frozen Bread.—During storage of bread in the frozen state, a whitened or opaque ring about $^{1}/_{4}$ in. in width sometimes develops in the crumb just beneath the crust. When bread is stored at +15° F., rings may begin to appear in two weeks; at +10° F. rings may be noted in about five weeks. At 0° F., ten weeks or longer elapse before the rings are noted. This whitening is associated with the movement of moisture by sublimation and diffusion of the moisture from the interior of the crumb to a region of lower moisture content just beneath the crust (Pence *et al.* 1958). Fluctuating temperatures especially at 10° F. or above, may accelerate this movement of moisture.

Because of the danger of the formation of these abnormal white rings when bread is held for a few weeks, it is of importance to maintain bread at a low storage temperature.

Defrosting

Rapid defrosting with moving air of low humidity is of great importance in maintaining the quality of frozen bread. Pence *et al.* (1956A) recommend refrosting bread with moving air (150 linear ft. per min.) at 120° F. and 50 to 60 per cent relative humidity. However, Barta (1958) of that laboratory (the Western Regional Research Laboratory), states that air at no less than 200 ft. per min. velocity and a relative humidity of 30 per cent or less should be used.

All are agreed that defrosting conditions should be such that no moisture condenses on the cold bread. In still air the rate of heat transfer is slow and consequently defrosting is very slow. Further, it is likely that moisture will condense on the bread, unless the relative humidity of the air is very low. At temperatures just below 32°F., staling is rapid (p. 535); therefore, it is important to thaw the bread and bring it rapidly to room temperature or slightly above. This can be done best with air of low humidity which circulates freely and uniformly around the product.

ROLLS

Dinner rolls are prepared by yeast fermentation and subsequent baking of dough in much the same way as bread; further their composition is much the same as bread. Consequently, rolls are subject to the same staling phenomena as bread. In general, freezing preservation of rolls has the same advantage as the freezing of bread. However, the homemaker can be sure of obtaining freshness in her rolls by the use of "brown and serve rolls," which are marketed without freezing.

Rolls to be frozen, should immediately after baking, be rapidly cooled, quick frozen and stored at a temperature of 0°F. or lower until needed. Then they should be rapidly thawed.

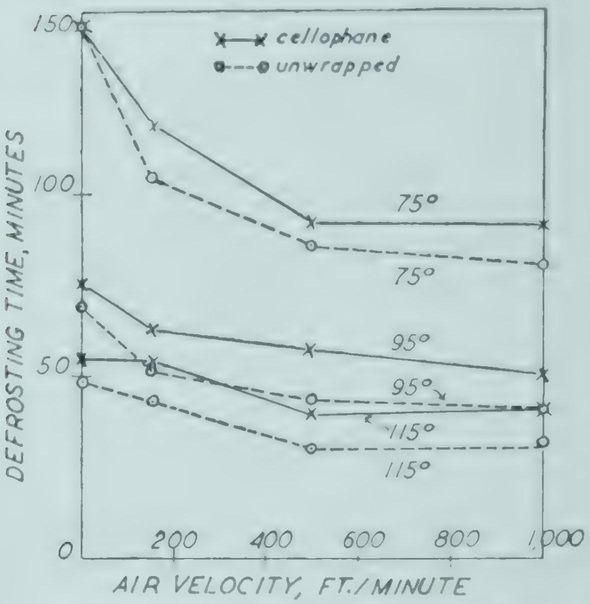
Rolls intended for freezing are usually either packed in waxed paperboard trays, overwrapped with moisture-proof Cellophane, or some other transparent moisture-proof sheeting, or heat-sealed in moisture-proof Cellophane bags.

Kulp and Bechtel (1958) have shown the great advantage of the use of a warm airblast (95°F.) for reducing the time required for the defrosting of dinner rolls (Fig. 151), both wrapped and unwrapped.

PIES

Commercially, most frozen pies are frozen before baking and in most instances are marketed in the solidly frozen condition. One company, however, prepares and freezes unbaked cream pies and apple turnovers in a central plant (see p. 534), then transports the frozen products to the branch retail bakeries where they are baked just before being sold at retail (Anon. 1959A). This in-store bakery operation costs somewhat more because of the extra freezing step, but this is counterbalanced by the fact that, when marketed in this way, losses because of stale baked goods are negligible.

Since this system of freezing of pies, turnovers, cake batters, etc., makes



Courtesy of American Institute of Baking

FIG. 151. EFFECT OF DEFROSTING TEMPERATURES ON THE DEFROSTING TIMES OF UNWRAPPED AND WRAPPED DINNER ROLLS AT AIR VELOCITIES FROM 0 TO 1000 LINEAR FT. PER MINUTE

it possible for the baker to sell baked goods with "just-out-of-the-oven" freshness, a brief consideration of the freezing of unbaked pies and batters is not out of place in this chapter.

Most pies are little changed by freezing, regardless of whether they have been baked or not. The filling of some custard pies becomes curdled or "separates" during freezing and thawing. Therefore, the freezing of custard pies should be thoroughly tested before planning freezing operations on a commercial scale.

Although pie dough is not greatly affected by freezing, there are other changes which may occur that should be considered before proceeding with commercial freezing operations. In the case of fruit pies, e.g. apple, peach and apricot, the fruit may darken because of oxidation. If the fruit has not been treated to prevent oxidative changes prior to its use, the slices of apples, peaches and apricots must be treated so as to inhibit or at least retard oxidation. Treatments commonly used include (1) steaming, (2) addition of ascorbic acid (pure vitamin C), and (3) treatment with a small amount of sulfur dioxide or a sulfite. For detailed information concerning these treatments, the reader is referred to the comprehensive treastise on food freezing, *The Freezing Preservation of Foods* (Tressler and Evers 1957).

In preparing either unbaked or baked fruit pies for freezing, the baker should use a jelling agent which will retain the proper consistency and clarity of filling and prevent the filling from soaking into the bottom crust, which may make it soggy, and make it impossible to obtain uniform browning of the bottom crust. The selection of the proper thickening agent is therefore of great importance. Waxy maize and specially modified starches, either alone or mixed with Irish moss extract, locust bean gum, or low-methoxyl pectin are recommended by Tressler and Evers (1957) who give many tested formulas.

The preparation of pie dough for pies to be frozen is not different from the practice followed in an up-to-date bakery. All of the ingredients should be at 60° to 65°F. The shortening, dry ingredients and water (or milk) should be combined with a minimum of mixing and handling. The dough should be measured and rolled with the least possible handling, and formed into pies in such a way as to have very little "scrap" left over.

Mince and pumpkin pies are commonly frozen before baking. On the other hand, chiffon pie fillings are placed in previously baked pie shells. When used by the homemaker, the chiffon pies need thawing only, since the filling has been cooked and the crust baked.

CAKES AND CAKE BATTERS

Almost all kinds of cakes can be frozen and thawed without notable change. However, the length of time that the frozen cake can be held in storage without marked deterioration varies greatly with the kind of cake.

Batters

Many kinds of batters can also be frozen without appreciable change; however, the storage life of many batters is short, unless special baking powder, which does not continue to react in the frozen cake, is used.

Cake Batters

Tressler and Evers (1957) report that yellow cake and gingerbread batters had a storage life of only 14 weeks. On the other hand, white and devil's-food cake batters produced good cakes after 34 weeks' storage at 0°F. Angel-food cake batter also has a long storage life. If special baking powders, which do not react until they are heated, are used, cakes containing baking powder will have a considerably longer storage life.

Cakes

Since only a few bakers freeze batters, but many freeze cakes, further discussion will be limited to the freezing of baked cakes. Although freezing is the best-known method of preserving cakes, some undesirable changes may occur in some cakes during freezing and subsequent storage. Chocolate cakes may lose volume during freezing and storage (Miller and Beattie 1949); the longer the storage period, the greater the volume loss may be. There may be some loss of volume during freezing and storage of other kinds of shortened cakes; but most workers agree that it is not a serious matter. Sponge and angel-food cakes do not ordinarily shrink in volume as do chocolate cakes (Anon. 1954C).

Yellow and poundcakes become a little firmer during freezing and thawing. Freezing affects the compressibility of chocolate and devil's-food cakes very little. Some workers have found that freezing and thawing actually improves the compressibility (softness) of sponge and angel-food cakes.

In the case of angel-food and chiffon cakes, Pence and Hanamoto (1959) could find no significant difference in firmness, flavor, or texture as a result of slow or rapid freezing when the samples were compared with each other or with control portions of the same cakes that had not been frozen.

Devil's-food cake becomes somewhat more crumbly during freezing and thawing. Glabau (1954) found that this change can be kept to a minimum by rapidly freezing the cake at −15° F. or lower.

Using a modified MacMichael viscosimeter as an instrument to determine tenderness, Glabau (Anon. 1954C) noted a decrease of tenderness of pound, yellow layer, and chocolate layer cake during freezing and thawing, no change in the tenderness of angel-food cake, and an increase in the tenderness of sponge cake.

Cake Scores.—Analyzing the results of the tests of many workers who have studied the freezing and thawing of cakes, after two weeks storage at 0° F., the scores of the thawed cakes are not much different from those of comparable freshly baked cakes, except in some instances the volume score is lower, and in others the cakes are downgraded because of texture differences.

Freezing Point of Cakes

The high sugar and soluble protein content and small "free" water in the cake crumb reduces the freezing point of most cakes to 15° F. and under. Pence and Hanamoto (1959) estimate the nominal freezing points of cakes as follows: chiffon 15°; angel-food 12.5°; yellow layer 3° to 5°; and pound 2° F. However, they indicate that "it must be emphasized that these nominal freezing points apply only to cakes having the same or closely similar composition to the ones used."

Storage Life of Frozen Cakes

The scores for appearance, color, flavor, tenderness and texture of most plain yellow and plain white shortened cakes do not drop greatly during 6 or 7 months storage at 0°F. (Meyer *et al.* 1953; Paul *et al.* 1954). Graul and Lowe (1947) recommend storage of frozen cakes at —10°F., since they found the cakes retained their flavor, color, and aroma better at this temperature than at the usual 0°F. storage temperature. The results of several studies have indicated that the type of shortening used has a direct influence on the retention of flavor during storage. Both Zaehringer and Mayfield (1951) and Meyer *et al.* (1953) found that cakes shortened with butter had the longest storage life. Zaehringer and Mayfield found that cakes made with lard were definitely of inferior flavor immediately after freezing and deteriorated further during storage.

Frozen spice cakes have a relatively short storage life when compared to most other cakes (Skarha and Van Duyne 1955A; Tressler and Evers 1957), and ordinarily should not be stored for longer than 4 or 5 weeks.

Meyer *et al.* (1953) have shown that while frozen egg-white sponge cakes retain their palatability almost perfectly, egg-yolk sponge cakes develop an undesirable off-flavor in about two months.

A summary of the data indicating the storage life of cakes of various kinds is presented in Table 78.

TABLE 78

LENGTH OF TIME WHICH VARIOUS KINDS OF CAKE RETAIN THEIR ACCEPTABILITY

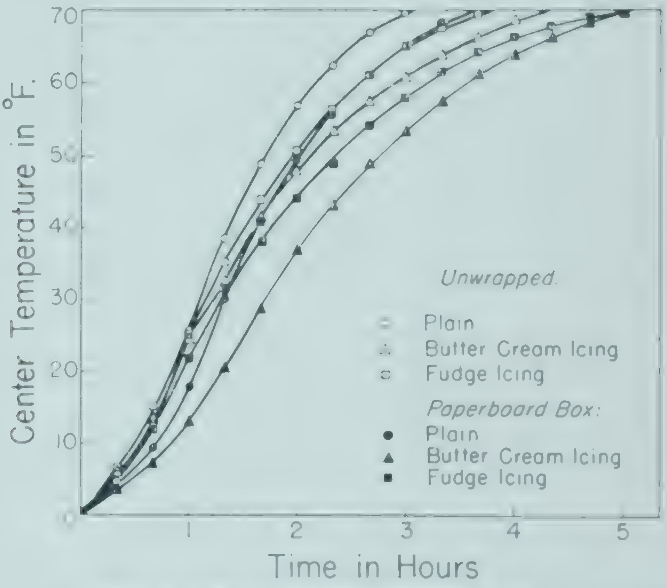
Kind of Cake	Temperature of Storage, °F.	Acceptability Retained, Months	Reference
Angel-food	−10° to 0°	4	Meyer *et al.* (1952)
Angel-food	−10° to 0°	6+	Meyer *et al.* (1953)
Cheesecake, French	−15°	9+	Beattie *et al.* (1949)
“Fathers Day”	−15°	14	Beattie *et al.* (1949)
Fruitcake	0°	12+	Anon. (1955)
Plain, yellow	0° to −10°	9+	Meyer *et al.* (1953)
“ “	−10°	4+	Zaehringer and Mayfield (1951)
“ “	−10°	8+	Graul and Lowe (1947)
“ “	0°	6+	Paul *et al.* (1954)
Plain, white	0°	7+	Paul *et al.* (1954)
Spice	+12°	4	Skarha and Van Duyne (1955A)
Sponge (egg yolk)	−10° to 0°	2	Meyer *et al.* (1953)
Sponge (whole egg)	−10° to 0°	6+	Meyer *et al.* (1953)

Frosted (Iced) Cakes

Freezing does not damage either the flat or the fondant type of icings. Unless the frosted cakes are properly packaged, however, moisture will condense on the surface of the frozen cake and damage the icing when it is brought out into a warm room. The colder the cake, and the higher the humidity, the greater the condensation on the cake, other conditions being the same.

Packaging

To prevent the condensation from damaging iced cakes, they must be packaged in a carton which is completely impervious to moisture (see below). Of course, the amount of condensation can be greatly reduced, and, perhaps completely eliminated by dehumidifying the air of the room into which the cake is placed after it has been removed from the freezer.



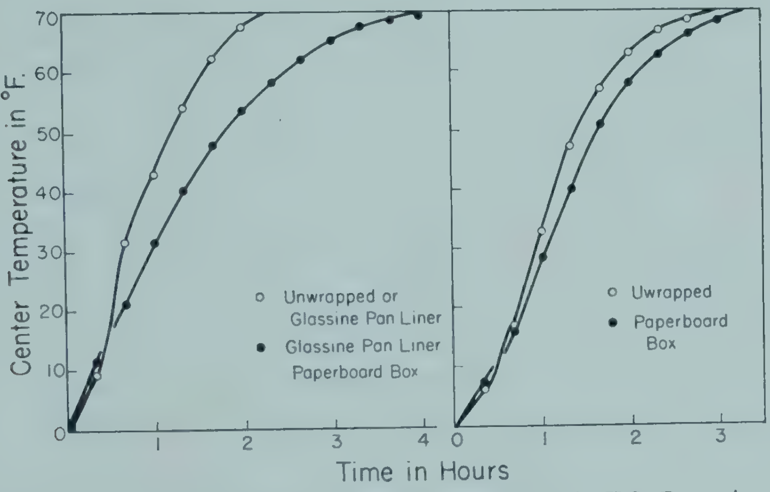
Courtesy of Western Utilization Research Branch, U.S. Dept. Agr.

Fig. 152. Warming Curves for 7-Inch Layer Cakes at 80°F. and About 150 Linear Ft. per Minute Air Velocity

Iced cakes should be allowed to thaw in the packages in which they were stored. Both the icing and packaging in paperboard boxes retard defrosting on account of their insulating value (see Fig. 152) according to Pence and Hanamoto (1959), icings on layer cakes prolong freezing or defrosting times nearly as much as paperboard cake boxes. Butter-cream icings provide more effective insulation than fudge-type icings.

Since all kinds of cakes tend to dry out during freezing and storage, and, as has been pointed out above, may be damaged by condensation when they are brought out of the freezer, both plain and iced cakes should be given proper protective packaging. Further, most cakes are rather fragile and so must be protected during handling. Cakes may be first wrapped in a heat-sealable moisture-vapor-proof sheeting such as polyethylene and then placed in a carton, preferably made of bleached sulfite board. Smaller cakes are often placed unwrapped in bleached sulfite cartons which are overwrapped and heat-sealed in a transparent moisture-vapor-proof sheeting, such as moisture-proof Cellophane or polyethylene. Although individually packaged cakes freeze more slowly than the unwrapped product (see Fig. 155), the difference in rate of freezing does not make a noticeable difference in the quality of the product, other conditions being the same (Pence and Hanamoto 1959).

However, if twelve poundcakes baked in aluminum foil pans, then closed with laminated-foil-waxed-paperboard lids, are packed and frozen in a corrugated fiberboard shipping carton, the rate of freezing is slowed to such an extent that the texture of poundcakes is adversely affected (Pence and Hanamoto 1959). In the case of angel-food, chiffon, and layer cakes there is no detectable difference between the slowly frozen cakes and those frozen rapidly. Even in the case of the slow frozen poundcake, it was superior to the day-old unfrozen cake. Further, the rate of freezing had no significant effect on the organoleptic properties of any of the cakes.



Courtesy of Western Regional Branch, U.S. Dept. Agr.

FIG. 153. WARMING CURVES FOR 9-INCH ANGEL FOOD (RIGHT) AND POUND CAKES (LEFT) AT 80°F. AND ABOUT 150 LINEAR FT. PER MINUTE AIR VELOCITY

Defrosting

It should be obvious that cake should be defrosted before it is served. And, of course, if the baker uses freezing as a means of preventing his cakes from becoming stale during either storage and or transportation and sells the cakes to his customers in the thawed condition, it is necessary for him to defrost his merchandise. Pence and Hanamoto (1959) have studied the rate of defrosting of plain and iced cakes (1) unwrapped and (2) in a "paperboard box" at 80° F. and about 150 feet per minute air velocity, conditions which they believe simulate those in the average kitchen. Their data are shown in Figs. 152 and 153. These data indicate that it takes about one and a half hours for an unwrapped cake to reach 50° and about three hours to warm to 70° F. Wrapped iced cakes required a half more time. Although 50° is somewhat too low a serving temperature, if the cake is sliced when the center is 50° F., the slices warm up in a few minutes to the prevailing room temperature.

If moving air at 100° F. is used, the time required for thawing unwrapped cakes and warming them to 50° F. is only about one-third of that needed at 80° F. air (velocity in both instances 150 feet per minute). In the case of packaged iced cakes the time required for defrosting is approximately cut in two.

COOKIES

Most cookies contain so little moisture that they can be frozen and thawed several times without affecting their quality. In general, the lower the storage temperature, the longer they can be kept in storage without noticeable deterioration. Most kinds of cookies retain their palatability for at least six months at 0° F., and considerably longer at lower temperatures (Beattie *et al.* 1949).

As is the case with cakes, it is of the greatest importance to package them so that they will not dry out during storage nor become soggy because of condensation during thawing.

MUFFINS

Freezing offers a means of preserving this product which does not retain its freshness when preserved in any other way. The storage life of most muffins is about six months at 0° F., and considerably longer at lower temperatures.

Aluminum foil packages are recommended so that they can be thawed and reheated in an oven without removal from the package.

WAFFLES AND PANCAKES

It is surprising that products which are as simple to make as waffles and pancakes are marketed successfully as frozen products. More than ten companies bake, pack, and sell products of this type.

The operations are simple. As a rule a dry mix is prepared in advance. This can be done in continuous, automatic equipment. Usually the batter is prepared in batches, using automatic mixing equipment. The batter is allowed to stand for a few minutes, after which the waffles are baked on thermostatically controlled waffle irons. The hot waffles are allowed to cool on trays and then slipped into transparent bags made of moisture-proof Cellophane, polyethylene or other moisture-vapor-proof sheeting, usually two waffles to the bag. The bags may be imprinted or printed labels may be slipped into each bag. The bags are closed, heat-sealed and stacked on trays which in turn are placed on wheeled racks and moved into an airblast freezer where the waffles are frozen at below zero, ordinarily in an airblast. After freezing, they should be packed in fiberboard containers and stored at 0°F. or lower.

Frozen waffles are easy to prepare for the table. They are reheated in an ordinary household toaster.

Pancake batter is usually prepared from a mix in much the same way as has been described for waffle batter. After baking, the pancakes are cooled, packaged and frozen much as waffles are. Most homemakers thaw and reheat them in the household toaster.

SHORTCAKES

Two companies are now preparing, packing and freezing strawberry shortcake on an important scale. Shortcakes are of two general types; in one the cake is a true cake, either the sponge type (angel-food, an egg-white sponge, or regular sponge, made with egg yolk or whole eggs), or a shortened cake made with whole eggs; in the other a rich biscuit dough is the cake.

The cakes now being packed and frozen are shortened "gold" cakes, either baked in small aluminum foil pans which are used as containers for the shortcakes or are ordinary baker's cakes cut to fit the package used for the shortcake.

The strawberry filling is prepared by thickening and sweetening either a strawberry purée or thawed sliced strawberries with a waxy maize starch or a modified starch.

Either whipped cream or an imitation whipped cream prepared from hydrogenated vegetable shortening may be used as a topping.

The closed packages are frozen, preferably in an airblast at below 0°F. Storage should be at a temperature not higher than 0°F.

Care should be taken in handling the product to be sure that the product does not warm above 5°F. At higher temperatures, it partially thaws with resultant rapid deterioration of quality.

OTHER FROZEN PASTRY PRODUCTS

Danish Pastry

Danish coffee rings, whipped cream cakes, triangles, apple combs (cockscombs), "scrubbing brushes" and "combs," cream buns, spandauers, birthday sugar pretzels, and other Danish pastries are not materially changed by freezing and thawing. However, owing to the butter and other unsaturated fats which they contain, they may become rancid if they are stored for longer than a few months at 0°F. For long storage, −10°F. or lower is required.

French Pastry

Most French pastries including cream puffs and chocolate éclairs can be quick frozen without marked change provided they are held at a uniformly low temperature. The pastry should be frozen rapidly immediately after filling, as otherwise the shells may become soggy. The sugar content of the fillings is usually high; consequently their thawing point is low. Some of them partially thaw at +5°F.; as a result, if the storage temperature fluctuates between +5° and 0°F. or thereabouts, each time the temperature rises to +5°F. a portion of the moisture in the filling thaws. This partial thawing and refreezing, repeated over and over again, may cause a change in texture of the filling. For this reason some bakers freeze only the pastry shells and fill them after thawing (Dressel 1952).

Cheesecake

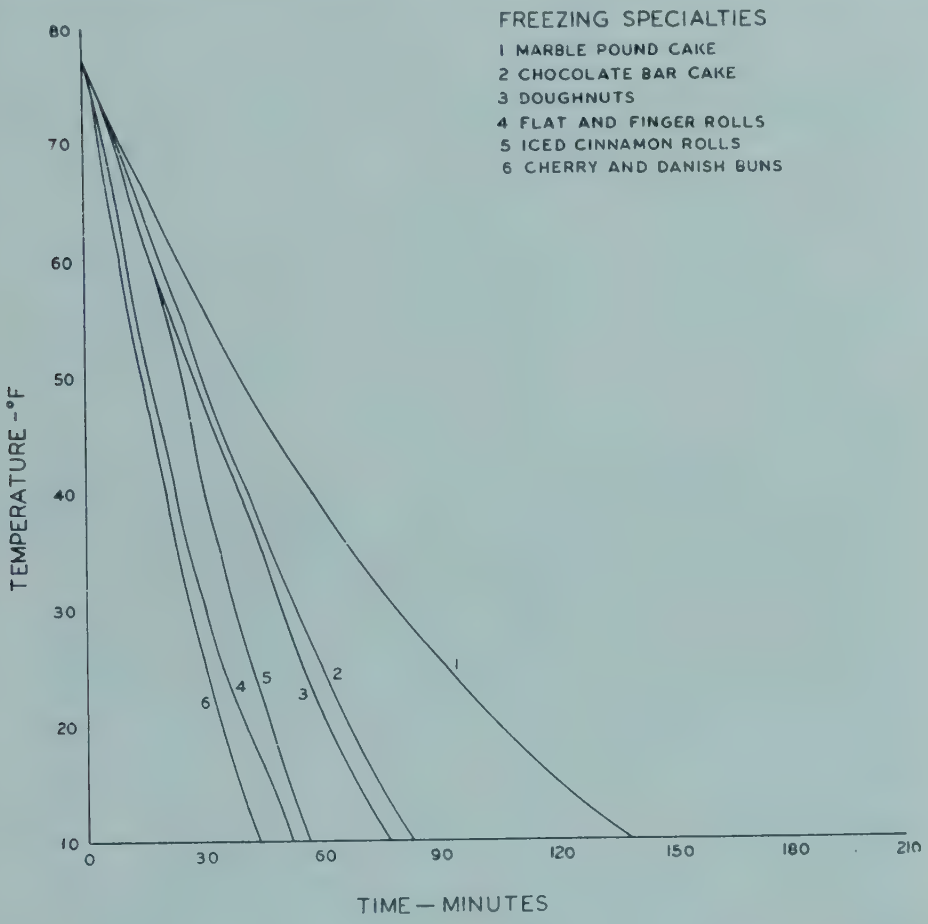
Cheesecake can be frozen and thawed without noticeable change of texture or flavor. A uniformly low temperature is desirable for this product, as it reduces the danger of storage changes.

Doughnuts

The common high shortening cake-doughnuts, made using baking powder as the leavening agent, may change slightly in texture and become somewhat crumbly after freezing and thawing, if they are not packed in moisture-vapor-proof packages prior to freezing so as to prevent desiccation. Further, this product is high in fat which may turn rancid if stored for longer than two months. However, much longer storage life may be obtained by the use of very stable hydrogenated shortening; and by storing them at −20°F. (Steinberg 1957). Because of this, a storage temperature of −10°F. or preferably lower is recommended for this type of doughnut.

Steinberg (1957) compared the staling of freshly baked and thawed doughnuts using both a trained panel and a compressimeter and found that both deteriorated at the same rate. Both the thawed and the control doughnuts were considered saleable after five days at 75°F.

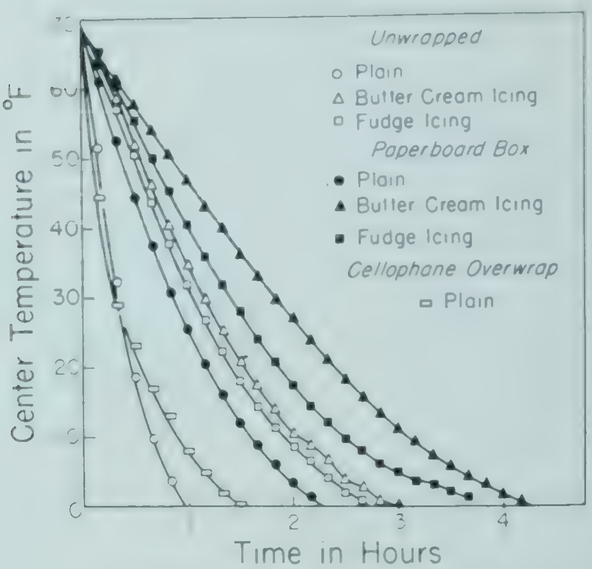
Unglazed raised doughnuts leavened with yeast are little changed by freezing and thawing, but should be stored at —10°F. if they are to be held long. However, glazed yeast doughnuts are changed in appearance by freezing and thawing (Steinberg 1957). Irregular white patches are formed on the glaze in about twelve hours at either 5° or 0°F.; at lower temperatures the patches form more quickly. Coated cake doughnuts are not damaged by freezing and thawing provided they are packaged in moisture-vapor-proof packages.



Courtesy of York Corp.

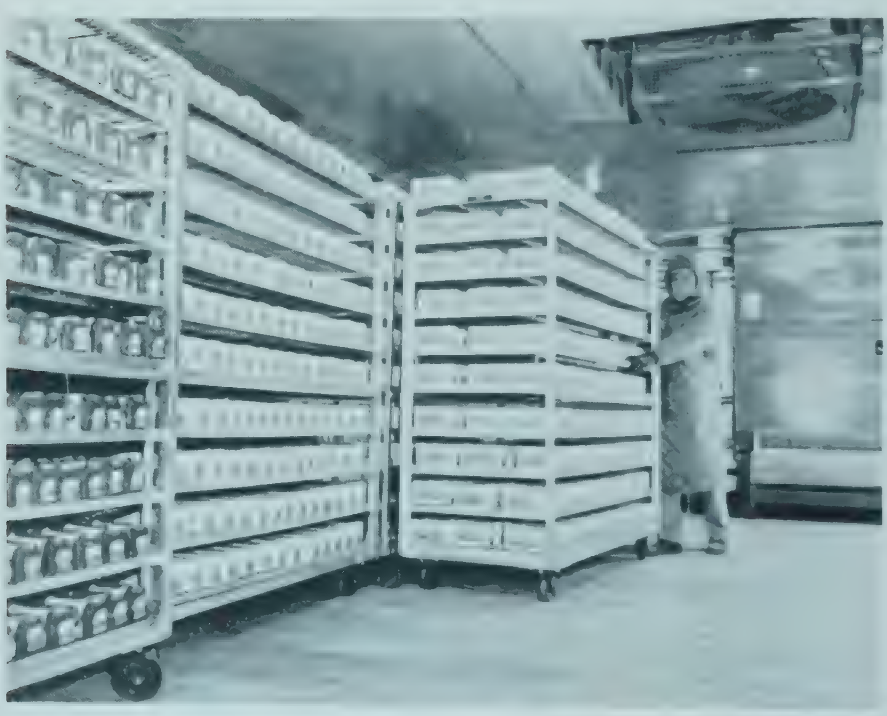
FIG. 154. FREEZING RATES OF WRAPPED DOUGHNUTS, CINNAMON ROLLS AND OTHER SPECIALTIES IN A YORK-UNION CONTINUOUS FREEZER AT —30°F.

Doughnuts and other small cakes and rolls freeze rapidly in an airblast such as is used in a York-Union freezer (see Fig. 154).



Courtesy of Western Regional Branch, U.S. Dept. Agr.

FIG. 155. COOLING CURVES FOR 7-INCH LAYER CAKES IN FREEZER AT —20°F. AND 650 FT. PER MINUTE AIR VELOCITY



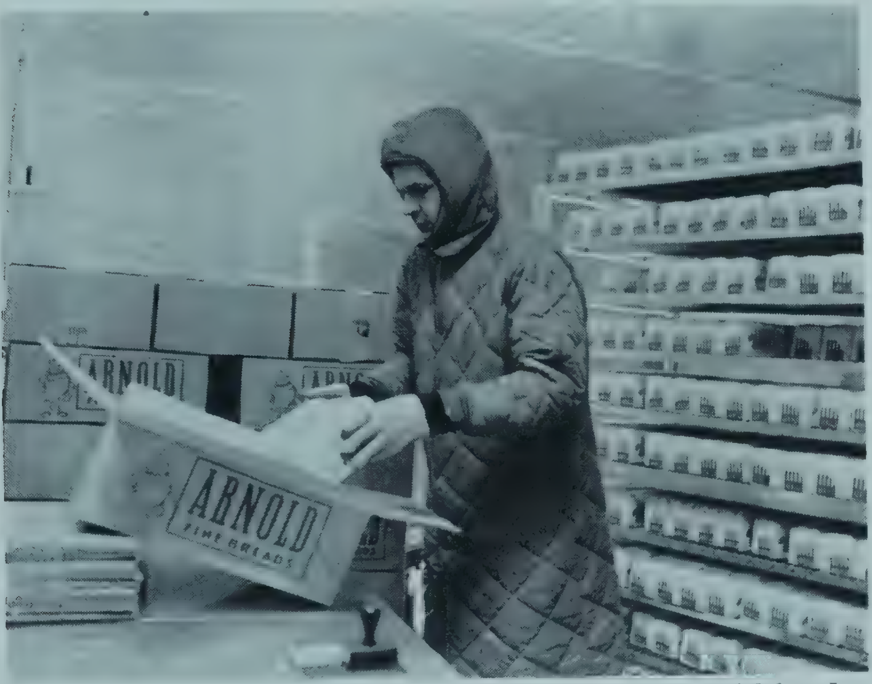
Courtesy of Arnold Bakers, Inc

FIG. 156. RACKS OF BREAD BEING QUICK FROZEN AT —20°F. IN THE QUICK FREEZING ROOM OF ARNOLD BAKERS, INC., PORT CHESTER, N. Y.

The bread is frozen shortly after being baked so that, when defrosted, it will retain the oven-fresh flavor, aroma, and other characteristics of newly-baked bread. The bread is put into the quick freezing room within 4 to 6 hours after being baked, normally cooked, and packaged in tightly sealed double wrappers.

EQUIPMENT FOR FREEZING BAKERY PRODUCTS

Most of the common types of freezers used for freezing fruits and vegetables are not designed to freeze bread, cake, pies, and other bakery products. None of the multiplate freezers (e.g., the Birdseye, the Amerio, and the Food Machinery freezer) is advantageously adapted to freeze bakery products.

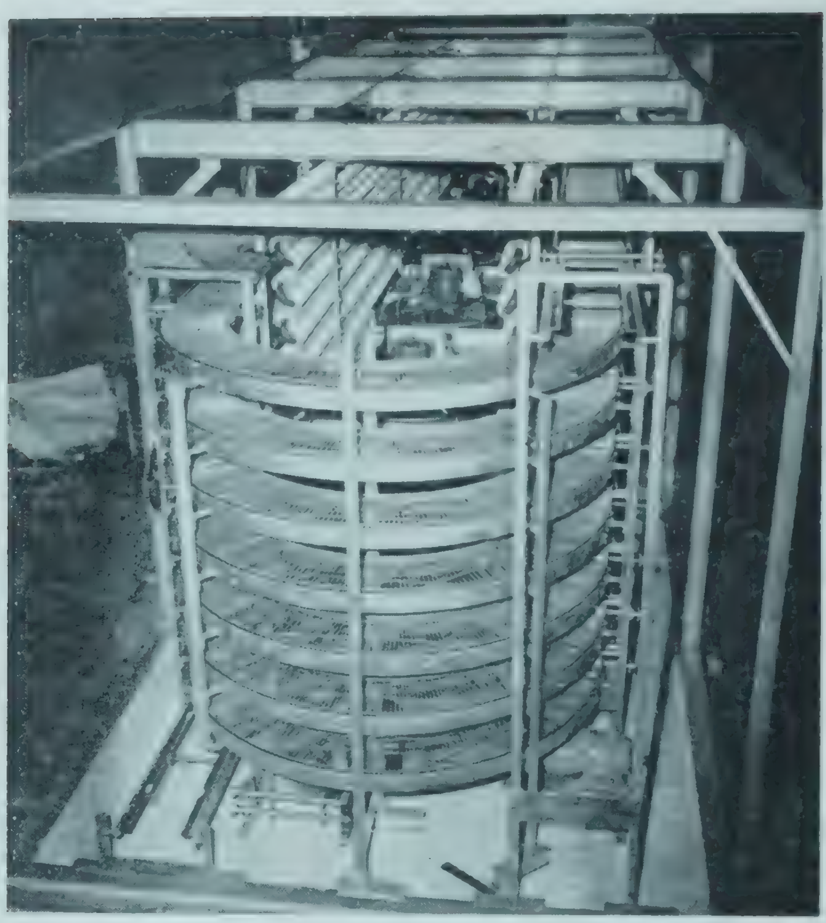


Courtesy of Arnold Bakers, Inc.

FIG. 157. PACKING FROZEN BREAD INTO CARTONS AT ARNOLD BAKERS, INC., PORT CHESTER, N. Y.

The simplest method of freezing baked goods is to place the products on large wheeled racks which are moved into a freezing room or a tunnel provided with powerful fans that blow cold air over and around the goods. A common airblast temperature is —20°F. Pence and Hanamoto (1959) have shown that the temperature of plain, unwrapped 7-inch layer cakes is brought down to 0°F. in less than one hour by a —20°F., 650 feet per minute airblast. Similar cakes packaged in paperboard boxes required slightly more than two hours to attain this temperature (see Fig. 155).

Arnold Bakers of Port Chester, New York, place freshly baked wrapped bread on wheeled racks, each 2 feet wide and 6 feet long holding 450 one-pound loaves. As soon as the temperature of the bread falls to about 80°F., the wheeled racks are pushed into a —22°F. freezing room (see



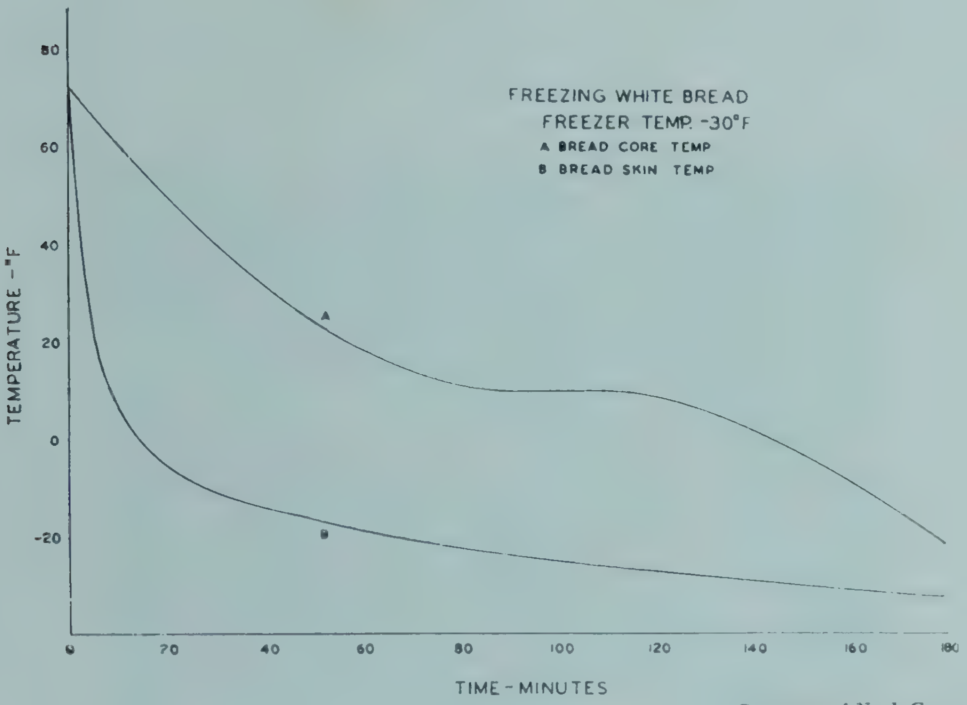
Courtesy of York Corp.

FIG. 158. THE YORK-UNION CONTINUOUS FREEZER WITH OUTER WALLS AND ROOF REMOVED, SHOWING CONVEYOR SYSTEM, FANS (CENTER) AND BANKS OF FREEZING COILS

This freezer was developed by the York Corporation with the cooperation of Union Steel Products Company. Freshly processed food is taken in on conveyors and is discharged solidly frozen to storage rooms. A unit 60 ft. long and 11 ft. high can freeze 3500 loaves of bread in an hour.

In this freezer, a compound compression system is used to produce the low temperature required for rapid freezing of bread. A rotary compressor is used for the low, or first stage compressor, and a reciprocating compressor is employed for the high or second stage. The high stage compressor discharges Freon gas under high pressure into a water-cooled condenser. The condensed Freon enters a receiver and is pumped from the receiver through coils. The low stage compressor removes the gas from the receiver and pumps it through an inter-stage cooler to the high stage compressor. The temperature of the coils is maintained at approximately −40°. A coil bank is placed along either side of the conveyor, air is circulated in the freezing tunnel by six fans which maintain a uniform temperature of −30°.

Fig. 156), equipped with "No-Frost" Niagara Blower coolers. Cold air is delivered into a plenum over a false ceiling. Fans located at the corners of the aisles formed by the bread racks distribute the air uniformly through the racks. When this room, which measures 40 feet by 40 feet, is fully loaded with bread, 4 to 6 hours are required for freezing.



Courtesy of York Corp.

FIG. 159. RATE OF FREEZING OF WRAPPED BREAD IN YORK-UNION CONTINUOUS FREEZER

These curves indicate that the "skin" temperature reaches the freezing point in less than ten minutes, whereas the core temperature does not reach the freezing point for about 90 minutes. Curve A also shows that once the core temperature has reached the freezing point, it will remain at that point for approximately 30 minutes before dropping further.

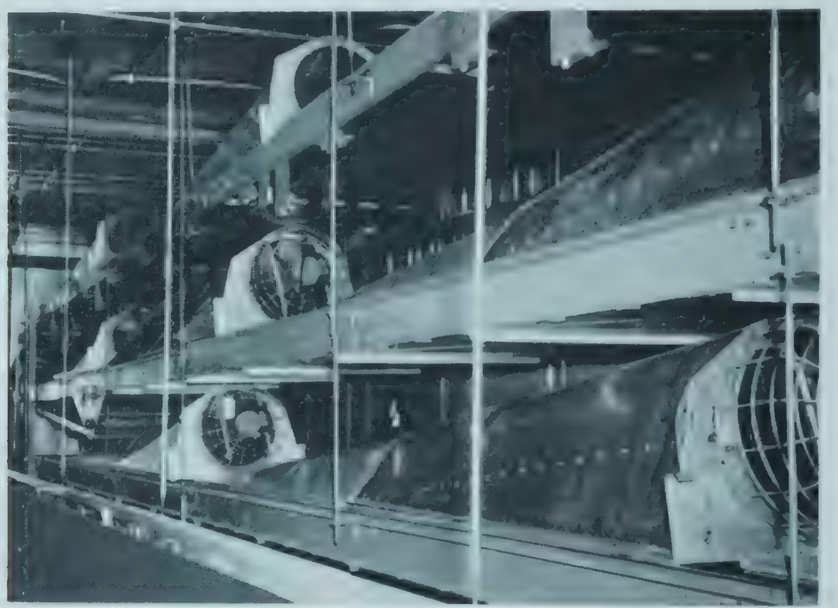
When the bread is frozen, the racks are wheeled out into a packing room where it is packed into sealed cartons (Fig. 157) for shipment or storage. This packing room is dehumidified and maintained at about 45°F. so as to prevent condensation of moisture on the wrapped bread.

The York-Union Continuous Bread Freezer

The York Corporation has cooperated with the Union Steel Products in the development of a freezer (no longer available) capable of handling simultaneously a variety of baked goods (Figs. 158 and 160) (Anon.

1956). The use of this continuous automatic freezer eliminates most of the labor required for the handling of bread frozen on racks. Wrapped or packaged baked goods roll onto the conveyor entering the freezer move slowly through the freezing tunnel until frozen, and then leave the freezer on a conveyor which transports it into cold storage.

Fig. 159 shows the rate of reduction of temperature of bread conveyed through the York-Union freezer operating at —30 F.; both the temperature of the "core" (center) and the "skin" (crust) of the loaf are given.



Courtesy Pepperidge Farm, Inc.

FIG. 160. BLOWERS AND DUCTS IN A NEW TYPE OF YORK FREEZER ESPECIALLY DESIGNED FOR THE FREEZING OF UNBAKED PASTRY

As ordinarily operated, temperature of the bread is reduced to 15° to 20 F. in the continuous freezer, then packed in fiberboard shipping containers and placed in a 0 F. storage until needed for shipment. Here the temperature of the bread drops to that of the storage room within a few hours.

The York-Union freezer is also used to freeze wrapped doughnuts, cinnamon rolls, finger rolls, Danish buns, pound and other small cakes. The freezing rates of these specialities are indicated in Fig. 154 (p. 553).

Continuous airblast freezers are also available in which the baked goods to be frozen are automatically loaded onto continuously moving trays. Blowers force air through the refrigeration coils and over the product (Spooner 1957).

STORAGE ROOMS

Most bakeries store frozen baked goods in commercial cold storage warehouses where the products are maintained at a uniform temperature of 0°F. Such storage facilities are available in all of the larger cities and also in many of the smaller towns.

Arnold Bakers, however, maintain their own cold storage room which is kept at a uniform 0°F. temperature by a Niagara "cooler" having four tons refrigeration capacity. The low temperature is maintained uniformly throughout the storage room by circulating 3,750 cu. ft. of cold air per minute.

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CHAPTER 21

David L. Diehl,
John Hansen,
and Samuel A. Matz

Slicing

SLICING THEORY[1]

Slicing is to the bread baker as frosting is to the cake baker. It is the finishing touch that often determines the acceptability of his product. A baker may use the highest quality ingredients and the best baking procedure, but his work will have been in vain if his bread is crushed and roughly sliced.

Once, when loaves were firm, slicing was not particularly a problem. But with the advent of the new "super-soft" loaves, slicing has become one of the baker's biggest problems. Many discriminating bakers found that their bread was being crushed and the fine, delicate structure destroyed during the slicing process. When confronted with this problem, it became necessary to engage in an experimental program to investigate the causes and determine the solutions of the difficulties.

Most of the research has been concentrated on the relationship of band characteristics to slicing performance.

To test band types, infeed rates, and band speeds, a test slicer was constructed as shown in Fig. 161. The test slicer was made from a modified band saw in which the saw blade had been replaced by a bread-slicing band.

On the table of the band saw was placed a carriage which was free to move perpendicularly to the band. As the carriage moved across the table, it moved a scriber across a rotating drum. This graphed a time vs. distance curve on cross-section paper.

As the resistance to slicing increased, it was noted that the time taken in slicing also increased. By comparing the times taken in slicing for different tooth forms, band speeds, infeed rates, etc., it was possible to tell what effect these variables had upon slicing.

After only a few tests, it was discovered that the softness of the loaf had a definite effect upon the ease of slicing. To keep the tests uniform, a method for determining the softness of the loaf of bread had to be devised. It was not enough merely to squeeze the loaf of bread to determine its softness. This allowed for too much human error. To one person

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David L. Diehl and John Hansen are associated with the Hansaloy Manufacturing Company.

[1] This section was contributed by David L. Diehl and John Hansen.

it might feel soft and to another—firm. This necessitated the invention of a softness gauge, which would give consistent values from one day to the next without the chance for human error. The softness gauge is illustrated in Fig. 162.

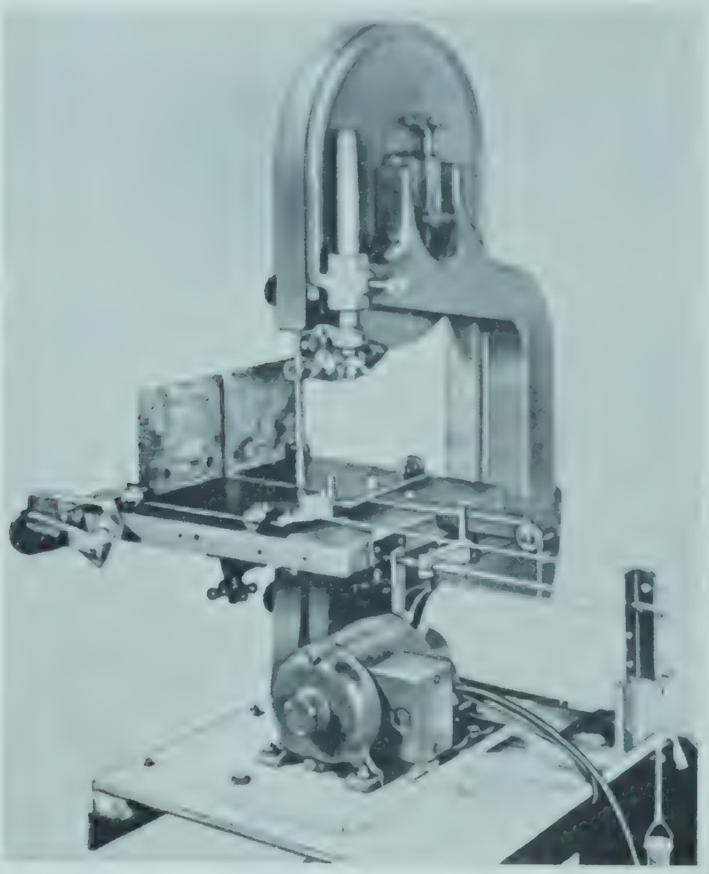


FIG. 161. TEST SLICING MACHINE

The kymograph is shown at the lower right of the picture, and the pressureboard for exerting a constant force against the loaf of bread is at the left center of the photograph.

This softness gauge consists of a three-ounce cone-shaped object which is allowed to sink into the bread. A scale on the stem registers in millimeters the depth to which it sinks. The softness gauge makes it possible to determine exactly how soft one loaf of bread is in relation to another.

This discussion is based upon the results obtained from the test slicer, experiments performed in the authors' shop using various types of commercial slicers, and actual field tests conducted at bakeries around the country. The authors have been collecting information on slicing since 1928, and within the last few years, experimentation has increased to meet the new problems connected with slicing the new "super-soft" loaves.

The secret of good slicing lies in the cutting band. It is made from a 7/16 inch wide, carbon-chromium-vanadium-steel strip, especially selected for its strength. These strips are cut into lengths with tolerances of about a thousandth of an inch. The ends of the strip are ground to form an overlapping joint, which is then silver-soldered on a special electronic induction heating unit. This heating unit allows the joint to be formed without exceeding the critical temperature of the steel. If the critical temperature of the steel is exceeded, the strength will be reduced, inviting breakage.

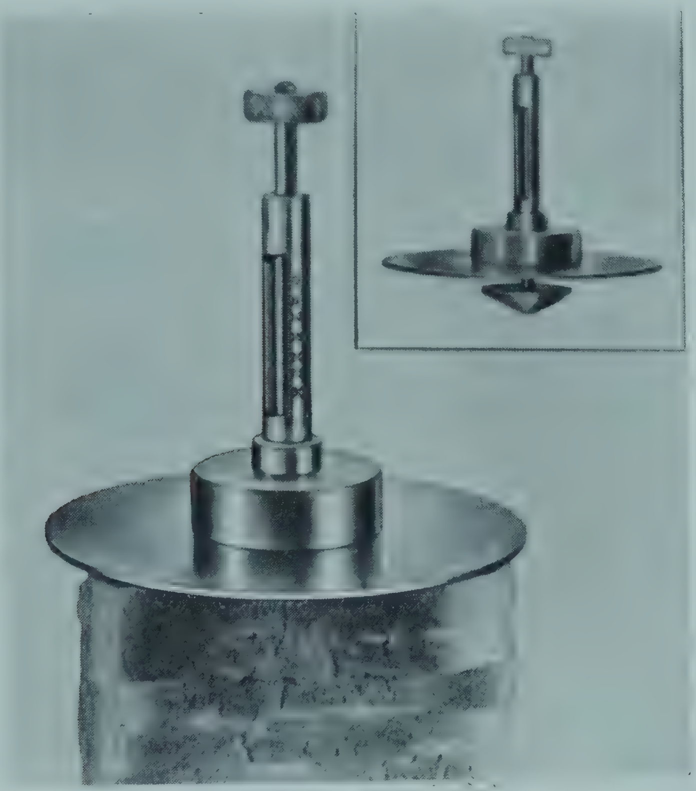


FIG. 162. SOFTNESS GAUGE FOR BREAD

On these bands, as they are now called, are ground the desired tooth forms and the necessary bevels. The bands are then honed to razor sharpness and packaged to be sent to various bakeries around the world.

When the bands are received at the bakeries, they are mounted on 2, 4, or 6 drums (depending upon the type of slicing machine) and crossed as in Fig. 163. From one drum to the other, each band is twisted through an angle of 180°. Midway between the two drums, is a point at which the two bands are perpendicular to the axis of the drums. Since there must be no twisting on that portion of the band which is doing the cutting, guides are introduced above and below the loaf to be cut.

Since the guides are exerting a force on the bands, the guides are subject to constant wear and must have extremely hard wearing surfaces. However, even with these hard surfaces, the friction between the bands and the guides will eventually cause wear. As a result, shoulders form in the guides as shown in Fig. 164. This situation can be helped by using new $^{7}/_{16}$ in bands for a time, and then using reground $^{5}/_{16}$ inch bands

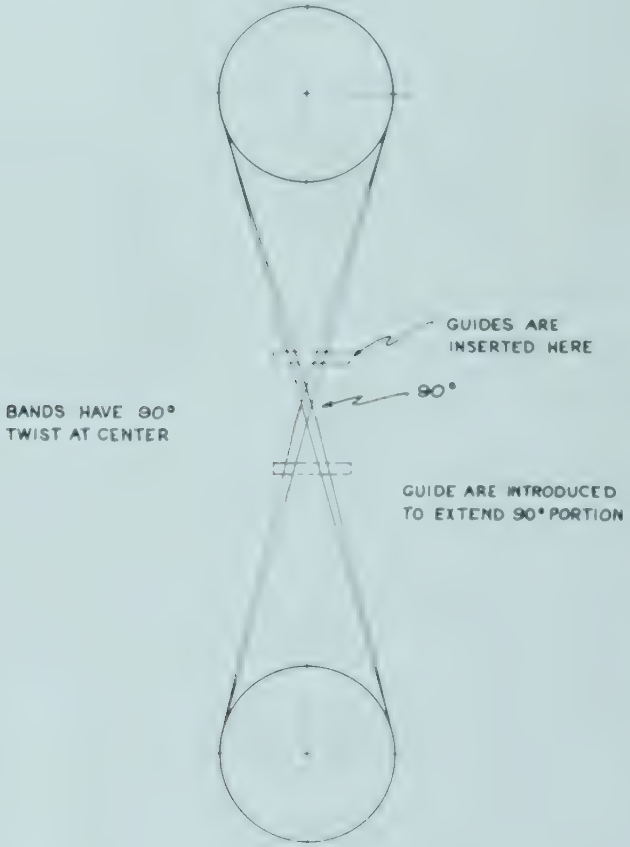


Fig. 163. Typical Arrangement of Drums, Bands, and Guides in Bread Slicers

for the rest of the time. This helps to distribute the wear more evenly over a greater area. If the depth of the shoulder becomes greater than one-half the width of the band, the teeth of the band will be knocked off. When this condition develops, the guides must be replaced.

To keep guide wear to a minimum, these six rules should be followed: (1) Distribute wear over the greatest possible area. (2) Allow a very small amount of play between the back-up roller and the band (if back-up roller is used). (3) Run the bands with the least possible tension for good slicing. (4) Do not allow crumbs to accumulate in the guides to

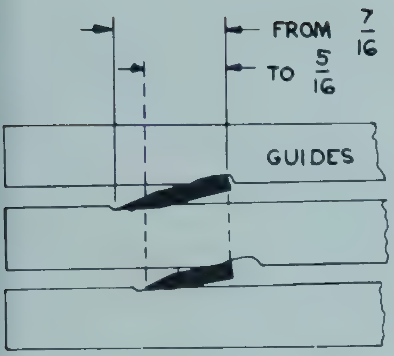
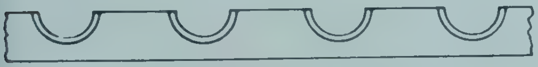
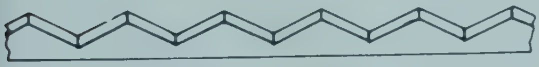


Fig. 164. Development of Shoulders in Band Guides

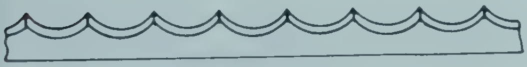
Long continued abrasion by the blades wears shoulders in the hardened steel guides. This condition can be partially alleviated by changing band widths from $^7/_{16}$ inch to $^5/_{16}$ inch after wear has occurred.



ALTERNATE SCALLOPS & FLATS



TWO BEVELED SERRATION



STANDARD SCALLOP

Fig. 165. Types of Tooth Forms Used on Bands

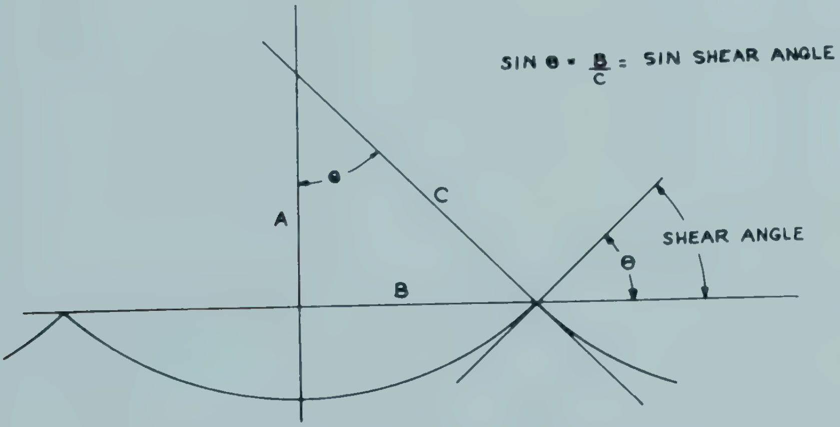


Fig. 166. Determining the Shear Angle

such an extent that the band cannot move freely, without undue amount of clearance. (5) Put a drop or two of divider oil on the guides every once and a while. (6) Alternate the direction in which the band points are pointing in successive set installations. In this way the guides will wear on both sides alternately. All points in the same set must, of course, be in the same direction.

There are, at present, three basic types of tooth forms being used. The three types are illustrated in Fig. 165. The first type is the alternating scallop-flat type. The second is the two bevel serration, and the third is the scallop type. The most common type is the scallop type. The authors manufacture only the scallop type because they believe it has several distinct advantages over the other two types.

It was stated earlier that to be efficient, a band must cut smoothly without crushing. It has been found that the crushing becomes less as the penetration becomes better. While experimenting with this type of band, it was observed that, as the scallops were made deeper, the penetration became better and the crushing decreased. However, there was more tearing and a rougher slice resulted. Conversely, as the scallops were made shallower, less penetration and more crushing was obtained, but a smoother slice resulted. In both cases, the sharpness of the cutting edges had to be equal. From these observations it was concluded that the efficiency of slicing is dependent somewhat upon the depth of the scallop. It was also found that the depth of the scallop must be maintained within fairly close limits.

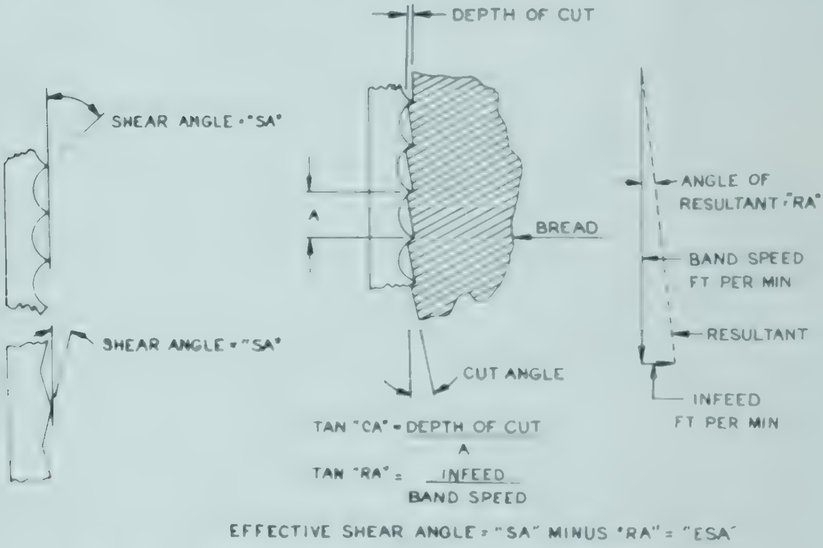

DEPTH OF CUT
SHEAR ANGLE = "SA"
SHEAR ANGLE = "SA"
A
BREAD
CUT ANGLE
ANGLE OF RESULTANT "RA"
BAND SPEED FT PER MIN
RESULTANT
INFEED FT PER MIN
TAN "CA" = DEPTH OF CUT / A
TAN "RA" = INFEED / BAND SPEED
EFFECTIVE SHEAR ANGLE = "SA" MINUS "RA" = "ESA"

Fig. 167. Angles Important in Slicer Performance

The relationship described above can be best explained in terms of what is called the "shear angle." The shear angle is formed by the angle formed by a line drawn tangent to the scallop and a line drawn across the top of the scallop. The shear angle is illustrated in Fig. 166.

Many experiments have been run using different shear angles and the results showed that it was necessary to work within fairly close limits. It has been proved experimentally that the upper and lower limits should be between 30° and 45° for efficient slicing. This, of course, means that any saw-tooth type of band would not work because the shear angle is greater than 90°. When the shear angle is less than 30°, crushing will occur sooner than with a greater shear angle. When the shear angle is greater than 45°, tearing occurs, resulting in a rough slice.

Several other angles are also important to slicing. These are illustrated in Fig. 167. The first is the cutting angle. The tangent of the cutting angle is equal to the depth of the cut divided by the distance between each tooth minus the distance from the point of contact with the bread. The smaller the cutting angle the smoother the slice.

Another important angle is the resultant angle. The tangent of the resultant angle is equal to the infeed divided by the band speed (both in feet per minute). The greater the resultant angle the less crushing will occur. The effective shear angle is then referred to as the shear angle minus the resultant angle. The effective shear angle must be great enough to accommodate the infeed plus the compression of the loaf due to the dullness of the edge, or crushing will again result. It has been concluded that if the effective shear angle is made smaller, without exceeding the limits previously established, a smoother slice will result.

There are various methods used in grinding the scallops or serrations forming the cutting edge. The scallops are produced by grinding two bevels in such a way that the resulting cutting edge is exactly in the middle of the steel. These two bevels are the "primary bevels."

The primary bevel is usually at about a six-degree angle with the side of the steel. This form has the strongest support of the cutting edge and is the most efficient cutting edge. The primary bevel will retain sharpness longer than either a 3 or 4 beveled edge. The main disadvantage of this type is that it is difficult to hone since much steel must be removed to sharpen the cutting edge. It is commonly used for slicing relatively firm loaves of bread. It makes a high pitched or hissing sound as it passes through the guides.

The next type of band is the three beveled band. This type of band has one primary bevel and two secondary bevels, one on each side. The secondary bevels are usually about one degree with the side of the steel. This type of band is generally used where a special type of honing is employed. It has the disadvantage that the cutting edge is at an angle with the cutting action.

The four-beveled form is the type which is becoming more and more popular with the bakers who are slicing soft or "super-soft" loaves. This type has two secondary, one degree bevels in addition to the primary bevels. The four beveled type has two distinct advantages over the other two types. The main function of the secondary bevel is to reduce the amount of steel to be honed off in order to sharpen the cutting edge. Also the vibrations and hissing sounds caused by the two beveled band moving through the guides are eliminated. A disadvantage is the loss in strength due to the removal of some of the steel supporting the cutting edge. This type of band is not recommended for the firmer loaves because it sometimes has a tendency to weave when it hits the crust, resulting in uneven slicing.

The four beveled bands are excellent for slicing the softer loaves.

So far, only the tooth forms and the various beveled edges have been considered. The smoothness of the cutting edge itself has not been considered. For many years the finished cutting edge was always ground at a 90° angle with respect to both primary and secondary bevels. Cross-grinding does not produce the smoothest cutting edge because the minute grooves or ridges that are left by the grinding wheel cause microscopic serrations where the two intersecting bevels form the cutting edge.

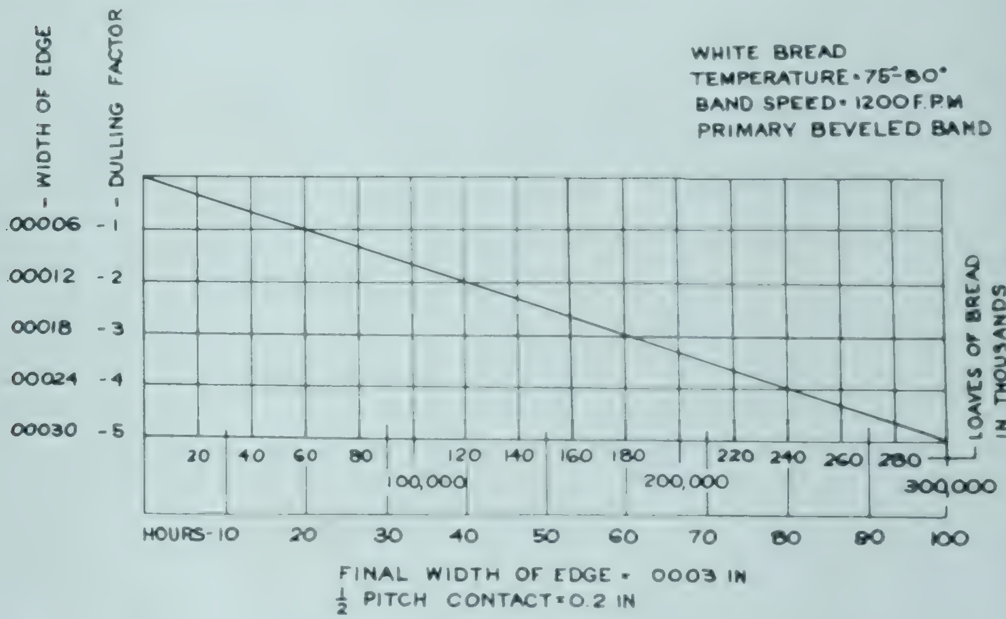


FIG. 168. RELATIONSHIP OF CUTTING EDGE WIDTH TO NUMBER OF LOAVES SLICED

When a tool grinder wants to put the best possible edge on a tool, he grinds and hones it parallel to the cutting action. Thus, when the best possible cutting edge is desired on a bread-slicing band, the final grinding and honing should be done parallel to the cutting action.

Experimentally, it has been found that the parallel ground band does a much better job of slicing softer, more delicate loaves, than does the cross-ground band. Efficient cutting is not done by burrs. The smoother the cutting edge, the more efficiently it will do its job. Therefore, for slicing extremely soft, delicate loaves, it is recommended that parallel ground bands be used.

Many bakers have had difficulty slicing raisin bread, honey bread, and pound cakes with conventional bread slicing bands. We have found that if the bands are coated with a special plastic coating, the efficiency in slicing will increase. These coatings are known commercially by the names of Teflon and Keflon. These coated bands have the ability to slip easily through the more sticky bakery products. These bands are initially more expensive but will give much better results.

Probably the most important single factor determining efficient slicing is the cutting edge thickness. When bands are new, for all practical purposes, the cutting edge may be considered to have no width. By flash electroplating various thicknesses of chromium on the cutting bands, it was found that when the cutting edge was 0.0003 inch, the band was too dull to give satisfactory results. Wear causes this thickness to occur after about 300,000 loaves or 100 hours of slicing; this is shown in Fig. 168. This thickness is less than one-tenth that of a human hair. So, it is necessary that the cutting edge be kept sharp or the bands must be replaced.

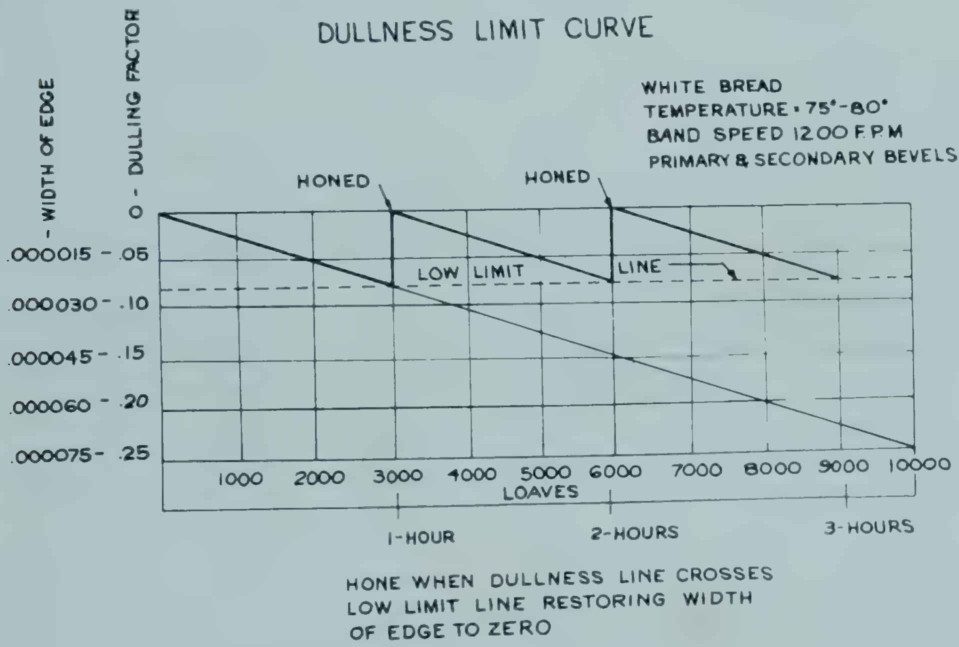


Fig. 169. Dullness Limit Curve

When the cutting edge thickness reaches 0.0003 inch, the bread is crushed excessively and the slice is rough. Therefore, this is the lower limit of dullness.

It will be observed that when the bands are sharp, very few flakes or "snow balls" are pulled out of the loaf. As the bands become more and more dull, more and more flakes are pulled out. These flakes can be observed on top of the loaf after slicing. It was noticed that after honing, these flakes would disappear and then slowly re-appear as more loaves were sliced. This led to the assumption that the number of flakes pulled out of the loaf was directly proportional to the sharpness of the cutting edge.

It has been found that conscientious bakers, and especially those who wrap their bread in cellophane, feel that a cutting edge of 0.00025 inch is too dull to meet their high standards. This value is less than one-tenth of the thickness that requires sharpening or new bands.

It was found that this low limit, illustrated in Fig. 169, was reached after about 3,000 loaves or after about one hour of slicing. Therefore, it is recommended that for the best possible slicing, the bands should be honed every hour.

With this new degree of sharpness demanded by many bakers, a practical method of honing had to be devised. This meant that the bands must be honed in the slicing machine. To meet this demand, three basic types of hones have been developed: (1) hand hone, (2) power hone, and (3) automatic hone.

Honing is a science in itself and probably one of the biggest maintenance problems to the modern baker. Of the three types of hones mentioned, the hand operated hone is probably the simplest type.

There are, of course, many hand-operated hones used today. One method being used at the present time employs cup wheels. This method of honing can only be used on a three beveled edge. This type of hone is simple to operate, but has several distinct disadvantages. Due to its construction it cannot possibly get down into the serrations, it can only hone the secondary bevel. Since it cannot hone down into the scallops, the tops will become flat and the band will lose the ability to penetrate. After a few honings, crushing occurs because of poor penetration.

Another method of hand operated honing consists of two diamond hones mounted in a holder, one hone for each side of the cutting edge. A spring forces the hone against the cutting edge. This sharpens the six-degree primary bevel, which is the proper angle to sharpen. This type of hone does get down into the scallop, due to the sideways movement and small radius, thereby honing that part of the scallop which takes the "bite" in the texture. There is, however, an inherent danger in this type of honing. The hone has a tendency, due to its construction, to chip small pieces of steel from the cutting edge. Some of these chips may find their way into the loaves. These chips also reduce the efficiency of the band. Every honing does not cause chips, but the danger of knocking steel out of the cutting edge is always present.

The third method of hand-honing is done with a small diameter, round stone, about $^{3}/_{8}$ or $^{5}/_{16}$ inch in diameter, which is held against the edges of the bands. Because of its light weight, it does a fairly good job. It will get down into the scallops and can be used with either 2 or 4 beveled edges. However, as with most hand-operated hones, it has one distinct disadvantage. To hone correctly the bands must be honed at the correct angle. This is hard to achieve with hand honing. In Fig. 170 is an illustration of the problem. If the hone is held at too small an angle, it will not touch the cutting edge. If the hone is held at too large an angle, the band will tend to cut the stone, thus dulling rather than sharpening it. If the hone should accidentally hook on one of the scallops, the band may break, endangering the operator.

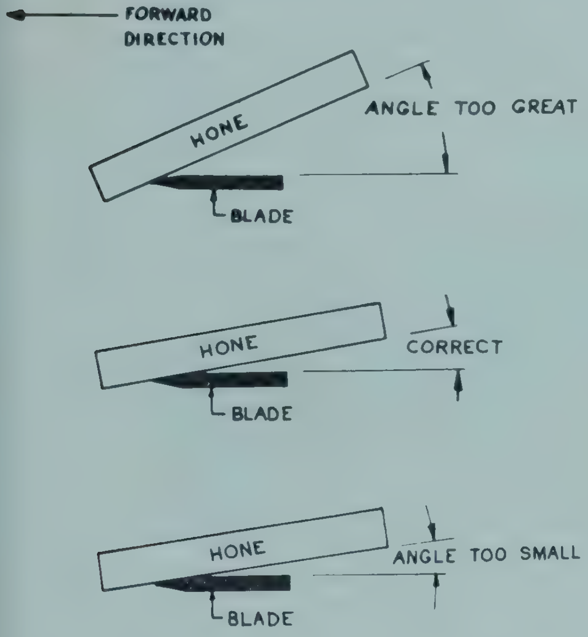


Fig. 170. Correct Honing Angle

When honing by this method, it is advisable to hold the hone lightly against the band at the bevel angle of about six degrees. The hone should bear a little harder against the actual cutting edge than the lower part of the bevel. The hone should be held lightly enough to let it vibrate as it passes over the scallops. The hone should be rotated slightly as it is moved forward. It should never be moved backward when in contact with the cutting edge.

The second major type of hone is the power hone, by which is meant a hone having an abrasive member or stone driven at a relatively high speed. The power hone is much less time-consuming than the previously mentioned hand-honing methods. However, an additional hazard results with the use of a power hone. Power honing, along with the possibility of chipping the cutting edge, produces emery dust. This emery dust, which consists of very hard, sharp particles, will embed themselves in the sides of the bands. As the bands pass through the guides, this embedded emery dust will lap the guides, increasing guide wear.

In every operation such as hand honing, there is always the "human element." There is always a chance that the operator may forget to hone or neglect to hone the bands until they have become too dull to be restored by honing.

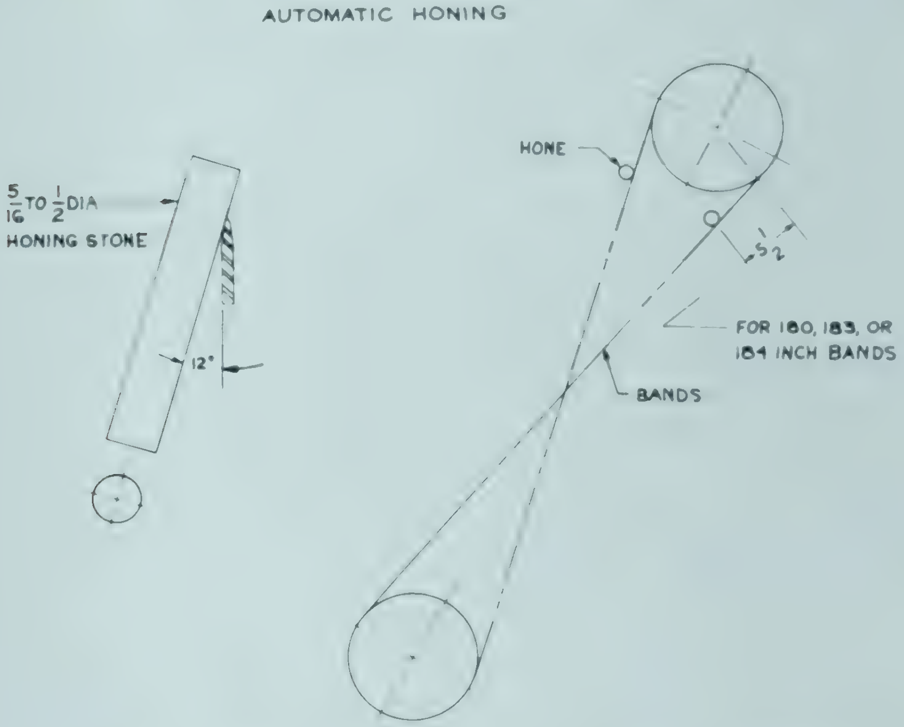


Fig. 171. Arrangement of Hones in Automatic Honing

In all types of hand honing, there is always the possibility of a band breaking, endangering the operator. When this occurs, no one can predict what will happen to the operator before the slicer can be stopped.

The third major type of hone is the automatic hone. Automatic honing has advanced with the other phases of automation in today's modern bakeries. It is the pinnacle of honing quality and practicality.

The automatic hone is the height of honing ease and safety. It removes the human element from honing, increasing quality and safety.

The automatic hone hones by the natural vibrations of the band itself, thus, the hone is able to get down into the scallop and practically retain the original tooth form.

The hone is located in the vicinity of the upper drum as shown in Fig. 171. About $5^{1}/_{2}$ inches down from the point where the band meets the drum, the band vibrates with sufficient amplitude so that if a stone is placed there, the vibration of the band will be such that it follows the stone. This allows the cutting edge to be honed down into the scallops. By this type of honing, the cutting characteristics that have been built into the band are not destroyed, only altered a very minimum.

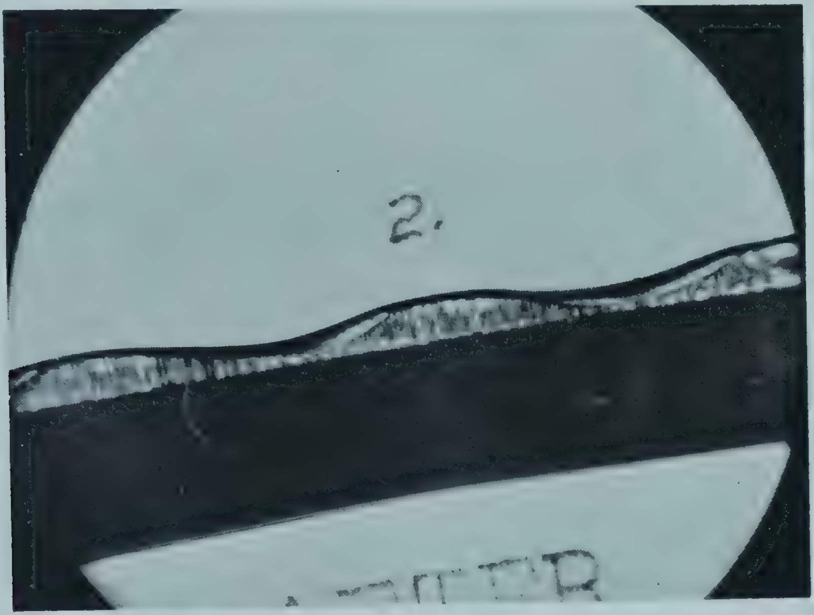


Fig. 172. Edge of Band Honed Continuously for Forty Hours

This automatically honed band still has a smooth edge, and no steel is missing from the cutting surface.

In Fig. 172 is an automatically honed band which has been honed continuously for 40 hours. The edge is still smooth, honing has been done down into the scallops, and there is no evidence of any steel missing from the cutting edge.

The hone can be actuated by either a push button or an electric timer, thus eliminating the chance of forgetting to hone. An electric timer brings the hone down and in contact with the bands. The hone contacts all the bands at one time and moves slowly back and forth to distribute the wear evenly over the stone. Since this type of honing removes only enough steel to restore the cutting edge, honing may take place without the fear of particles finding their way into the loaves. Honing with the automatic hone is done for about one-half minute, every hour.

There has been some question as to what temperature the bread should be sliced. As a general rule, it can be stated "the cooler the better."

Bread should not be sliced at a temperature greater than 110 F. under normal slicing conditions. If it is sliced warmer than this (at least in slicers with crossed bands) the bread may be crushed and the slices will be rough. As the bread cools below 110 F., the bread will become easier to slice until it reaches about room temperature, where further cooling has little effect.

Band tension is a very elusive quantity. Many bakers have the impression that uneven slicing can be corrected by increasing the tension. This is not the case. A loaf of bread is so soft that it does not deflect the band to any appreciable degree. Uneven slicing is caused by either guide wear or play developed in the guide supports.

It is very difficult to establish the exact amount of tension in the bands in a slicer. It is impossible for the slicer manufacturer to produce a drum that has exactly the same diameter all the way across. It is equally impossible for the band manufacturer to make every band of exactly the same length.

If we assume that the drum is 0.0001 inch smaller in diameter where one band runs than it is where an adjacent band is running, this band has to advance about one inch farther for every 400 revolutions. The band traveling the greater distance will increase its tension (in the trailing course) until one of two things happen. Either the band breaks or it must slip on the drum, equalizing the tension. If the band cannot slip before the ultimate strength of the band is reached, the band will break.

Guide wear is also increased by too much tension. When the tension is lessened, the guide wear will be reduced to a minimum.

Several gauges are available to measure the tension in the band, but they measure tension only; they do not allow for torsion, twisting, rubbing, and traveling. Although the steel band will break at about 2,000 lbs. straight tension pull, it is recommended that the tension not exceed 80 lbs. When the tension is measured both courses of the same band should be tested, often they will be different. Neither course should be allowed to exceed the maximum 80 lbs.

Slicer and band manufacturers are not the worst offenders in respect to variation of drum and band diameters. If crumbs are permitted to accumulate on the band or on the drum in such a way that they can get caught between the band and the drum, increasing the diameter, the tension will be increased. To prevent this, the slicers should be kept as immaculately clean on the inside as they are on the outside. No heels should be on the top of the lower drum after cleaning because when the slicer is started, they will ride around the drum between it and the band. If this happens chances are that the band will break because the steel used for the band is made of an alloy that has very little capacity for elongation. Crumbs and heels should be kept away from the lower drum to prevent breakage.

Factors contributing to the variation in tension are as follows: (1) the drums are not exactly the same diameter from end to end; (2) the drums are not perfectly round; (3) the two drums are not exactly parallel; (4) the bands are not in their proper slot in the guides; and (5) crumbs have been allowed to accumulate on the drums.

There are several basic requirements that must be met in order to obtain maximum efficiency from a slicing machine. The right bands for the right type of loaf being sliced must be selected. The two beveled edge should be used for the firmer loaves and the four beveled edge for the softer loaves. The blades should be honed correctly and as often as necessary to maintain maximum smoothness of slice. The slicer should be kept clean inside as well as out and checked to make sure that the bands are not under too much tension. There is probably not another piece of equipment or machinery in the bakery subjected to more complex stresses and loads than that thin band of steel which does the slicing in a band slicer. It deserves the best of care.

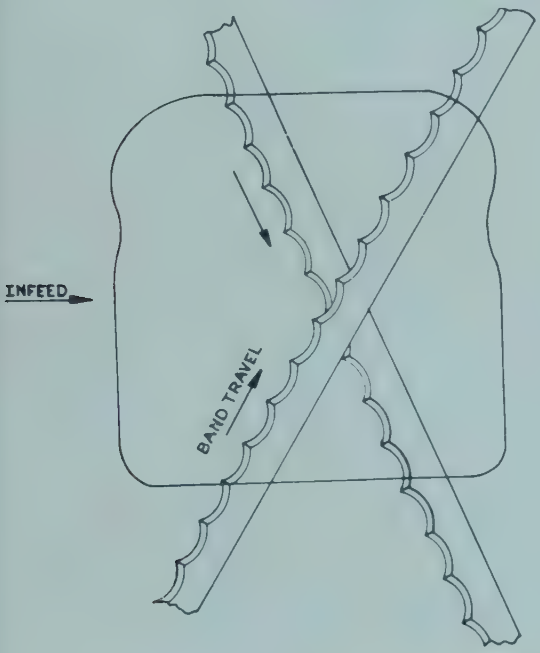


Fig. 173. Relationship of Bands and Bread in a Two-Drum Slicer

Most slicers of today are of the two drum type using crossed bands. Because of the characteristics of the two drum machines the cross is quite open. See Fig 173.

The texture of the "whipped batter" or "continuous mix" bread is such that it has a tendency to cling to the bands. Assuming that 20 bands are used to slice a given loaf and that each band is 0.015 in thick, then the thickness of the steel forced into the loaf is 20 × 0.015 or 0.300 inch everywhere except at the cross where we have 40 bands or 40 × 0.015 inch or 0.600 inch of steel.

Since the bands are running in opposite directions and it is often assumed that this equalizes the forces within the loaf; such is not always the case. If the friction of one band going into the cross for some reason is increased over the adjacent band going away from the cross, equilibrium has been destroyed and all the bands going into the cross in the same direction will cause the loaf to collapse. Sometimes the loaf is collapsed against the upper plate and sometimes against the lower plate, depending upon which direction got the upper hand. Collapsing is also apt to happen with Pullman loaves.

The theory has been developed that forces of slicing should be equalized within the loaf being sliced and not transmitted to supports and hold down plates.

To prove this theory, many tests have been conducted on multiple drum slicers with bands practically parallel in the cutting zone. Extremely soft bread has been sliced at 150 F. 300 loaves per minute (4-inch loaves), band speed of 1200 feet per minute, four beveled cutting edge, with no crushing and with extremely smooth slices. When the infeed was slowed down to less than 100 loaves per minute, excessive roughness of slice occurred. Since a noncrushing, smooth slice was obtained, we assume that the theory is correct.

The success of this fast slicing must, no doubt, in some measure be attributed to the resistance to motion of the bread crumb itself. The time element of slicing is so short that the texture does not have time to move. It is on the same order as pulling a table cloth from under dishes and having them remain on the table.

Judging by still incomplete tests up to this time, it appears as if the effective shear angle and tooth form has less effect than in conventional slicing. Also sharpness of the cutting edge is perhaps of greater importance.

Much experimenting and research must be done before slicing at these speeds and temperatures can be carried out in practice. However, the slicing, itself, looks very promising, in fact, it has been proven almost beyond doubt.

SLICING PRACTICE[2]

The preceding section written by Messrs. David Diehl and John Hansen, dealt with the theory of slicer band engineering. The present

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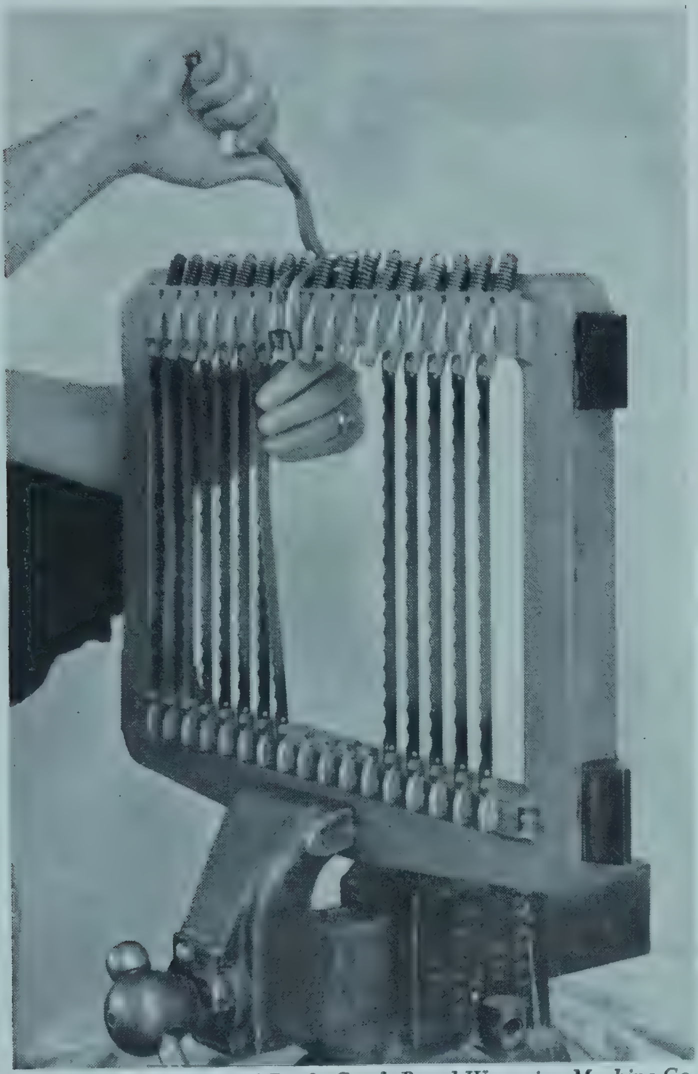
[2] This section was contributed by Samuel A. Matz.



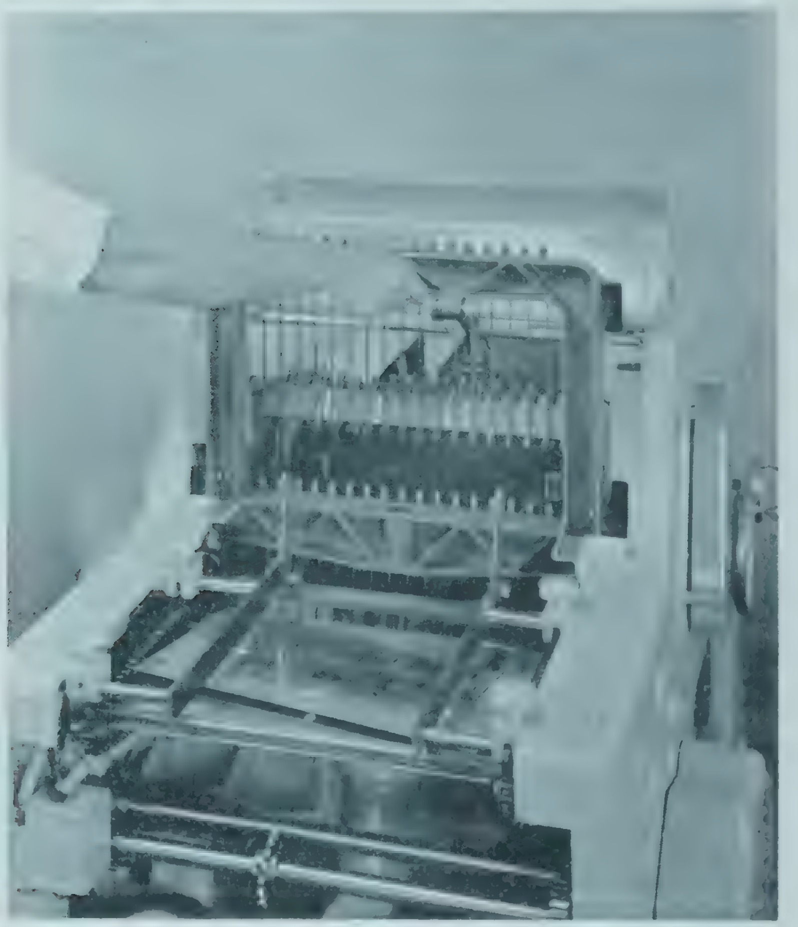
Courtesy of Battle Creek Bread Wrapping Machine Co.

FIG. 174. PLACING A BLADE INTO THE FRAME OF A RECIPROCATING SLICER

discussion will be concerned with slicing practice and with some of the machines available to the industry.

Slicers for bakery products can be classified into three categories based upon the type of cutting mechanism employed: (1) slicers using circular blades; (2) slicers using straight blades; and (3) slicers using continuous band blades. The first type is used only on rolls, buns, and similar pieces. Today, most white pan bread is sliced on machines using endless blades but a considerable number of reciprocating slicers (using straight blades) are in use, particularly for specialty breads.

According to Hartman (1948), bread has been sliced on a commercial basis only for the last 30 to 35 years. The first production scale slicers were based upon the reciprocal principle and would slice about 20 to 25 loaves of bread per minute. After the bread was sliced, it had to be placed in a cardboard tray or bound with a paper circlet to keep it intact through the wrapping cycle. After the first models had been in operation for about two years, the manufacturers of wrapping machines made improvements in their devices which made it possible to wrap sliced loaves not held together by trays or bands.



Courtesy of Battle Creek Bread Wrapping Machine Co.

FIG. 175. INSERTING THE BLADE FRAME INTO A RECIPROCATING SLICER

The initial improvements in slicers were designed to increase the speed of output so that one slicer could be used per wrapping machine. The latter devices commonly handled 40 to 50 loaves per minute.

About eight years after reciprocal slicers were introduced, Hartman developed and put on the market a slicer using continuous blades. This type of machine became popular very quickly and now is used almost exclusively for rapid slicing of white pan bread.

Reciprocal Slicing Machines

When band machines are used for slicing raisin bread, the sticky substances from the interior of the fruit are collected by the blades and deposited on the drums. Eventually, the deposit reaches such an extent that operation of the machine is interfered with and the bands may even be broken. Therefore, reciprocating machines are indispensable for slicing raisin breads or any product with a soft and sticky crumb. They are also much used for slicing hard-crust breads such as French or Italian, iced loaves, and heavy rye and health breads (Willson 1948). On the whole, machines of the reciprocating type can be said to be more versatile but less efficient than band slicers. As mentioned by Diehl and Hansen, it may be possible to overcome some of the crumb pick-up of continuous blades by coating them with Teflon and Keflon.

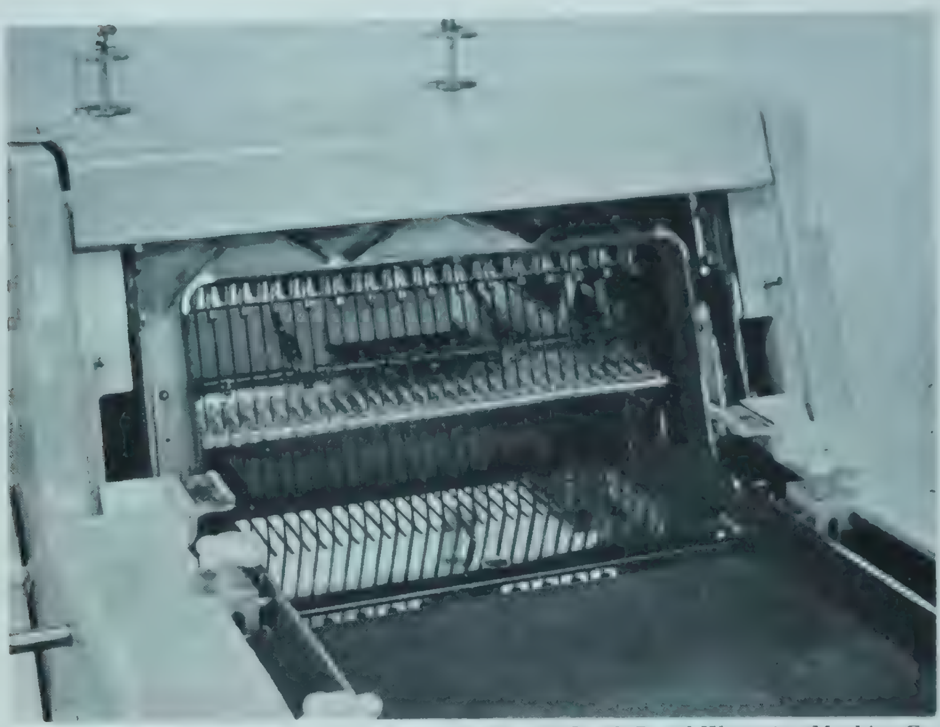
Fig. 174 illustrates the method of inserting blades in the frame of a reciprocating slicer. Each of the blades is held taut by the force exerted by a heavy spring. When inserting a blade, its spring is depressed by a special tool, allowing the blade pin to be slipped into the appropriate retaining notch.

Fig. 175 shows the procedure employed in fitting a blade frame into the machine. The frame shown here is made of cast magnesium permitting achievement of satisfactory strength with a weight of about $10^1/_2$ pounds. Frames are available for slice thicknesses of $^3/_8$, $^7/_{16}$, $^1/_2$, or $^9/_{16}$ inch. The time required to replace a frame is said to be on the order of 5 to 8 minutes.

In Fig. 176 is illustrated the slicing zone and compressor of a typical reciprocating slicer. In this model, the knife frames are tilted 20° toward the top crust of the loaf to provide angle cutting and to accommodate the natural flow of bread through the knives. Other manufacturers arrange the knife frames perpendicular to the floor but have the entrance conveyor slanted so that the top crust of the loaves encounters the knives first.

The up-and-down motion of the blades in this type of machine is transmitted from the motor to the blade frame by a chankshaft and levers. The vibration created by this motion has been one of the main objections to the use of reciprocating slicers. However, machines of modern design are constructed so as to minimize the noise and vibration, and these factors should no longer be considered major objections to the use of these machines.

A disadvantage encountered in using reciprocal slicers for soft white loaves is that the surface of the bread slice may exhibit slight waves or corrugations. This is usually objectionable to the production super-



Courtesy of Battle Creek Bread Wrapping Machine Co

FIG. 176. THE CUTTING ZONE OF A RECIPROCATING SLICER

A Model 5-C cake slicing machine is illustrated.

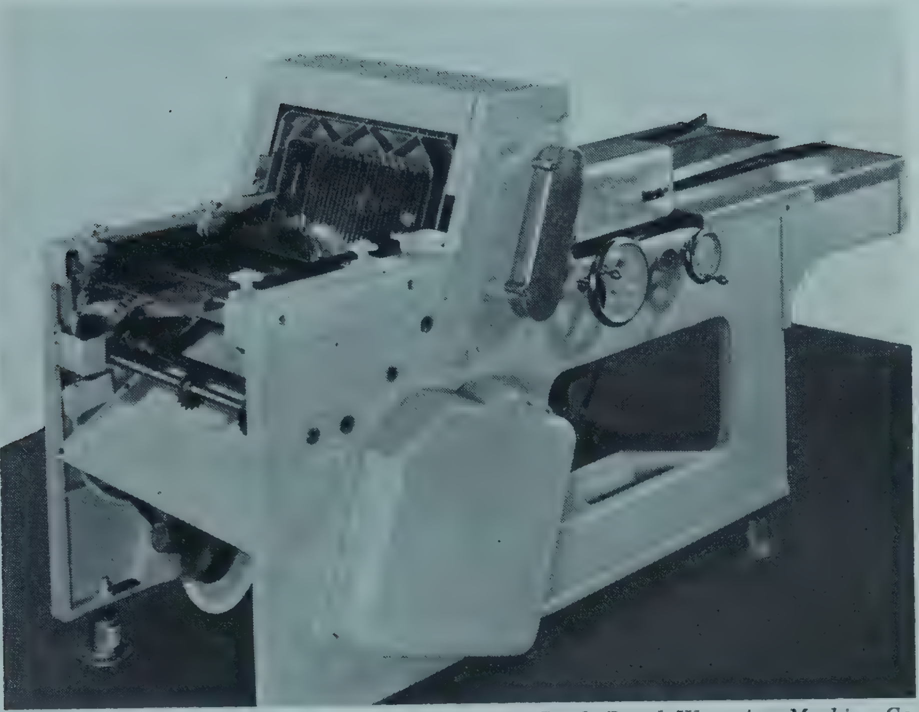
intendent and may even be so to the consumer. The effect is much less noticeable on denser varieties such as rye and health breads.

According to Hartman (1948) knives in reciprocating slicers attain a maximum lineal travel of 350 feet per minute and will slice from 10,000 to 20,000 loaves of bread without resharpening. This is much less than the service obtained with continuous bands, of course.

Band Slicers

Slicing machines using continuous blades are the preferred type for slicing uniform loaves of white bread at high rates of speed. They are also usable for many other types of bakery foods, but as the products begin to assume irregular shapes or to have sticky or heavy crumb their utility decreases. Some of the advantages of the band-type slicers are: (1) no vibration, (2) greater cutting speed, (3) less frequent need for blade sharpening, and (5) continuously variable slice thickness, within limits.

The principle of the endless blade slicer requires that the bands be placed around steel cylinders and crossed in the center so that they form a figure eight as viewed from the side of the machine. The bread contact area is at the point where the blades cross. Since the blades must

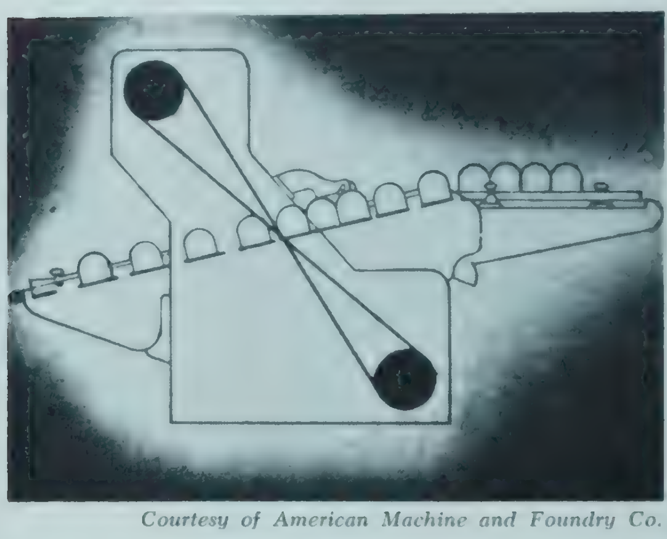


Courtesy of Battle Creek Bread Wrapping Machine Co.

Fig. 177. Continuous Flow Bread Slicer Showing Discharge Transfer, Knife Frames, and Adjusting Band Wheels

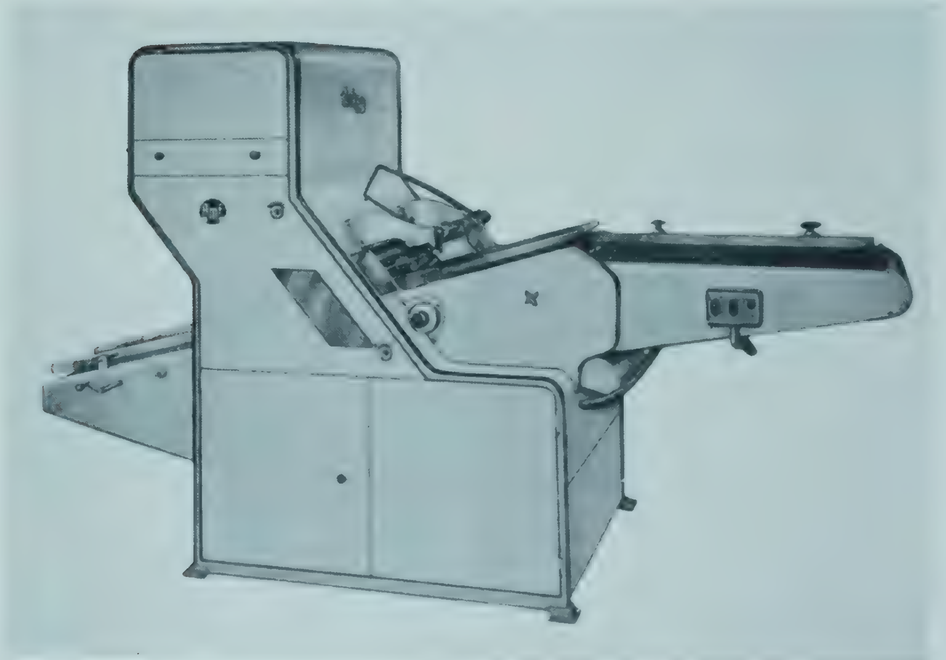
pass over the drums in a flat position and yet must present their serrated edges to the bread, it is necessary to turn them through a 90° angle between the time they leave the drum surface and the time they meet the bread. This turning function is performed by hardened steel guides located above and below the line of travel of the bread. These three types of elements—(1) two drums, (2) a required number of blades, and (3) four guides per blade—are the essentials found in every type of continuous blade slicer.

According to Hartman (1948), the first band slicer had close drum centers and an overall height of about six feet. After these machines had been in operation for some time, it was found that the drums were too close together, causing a too abrupt twist in the blades as they were turned through a total of 180° between the upper and the lower drums and creating too much pressure on the knife guides. As a result, the guides and bands overheated and suffered excessive wear and breakage. Experimentation with various band lengths resulted in the conclusion that drum centers about seven feet apart would give a band twist sufficiently gradual to eliminate excessive heat generation in the knife guides. Slicers with drums placed far apart also have the advantage that the longer blades require replacement or re-sharpening less often, saving



Courtesy of American Machine and Foundry Co.

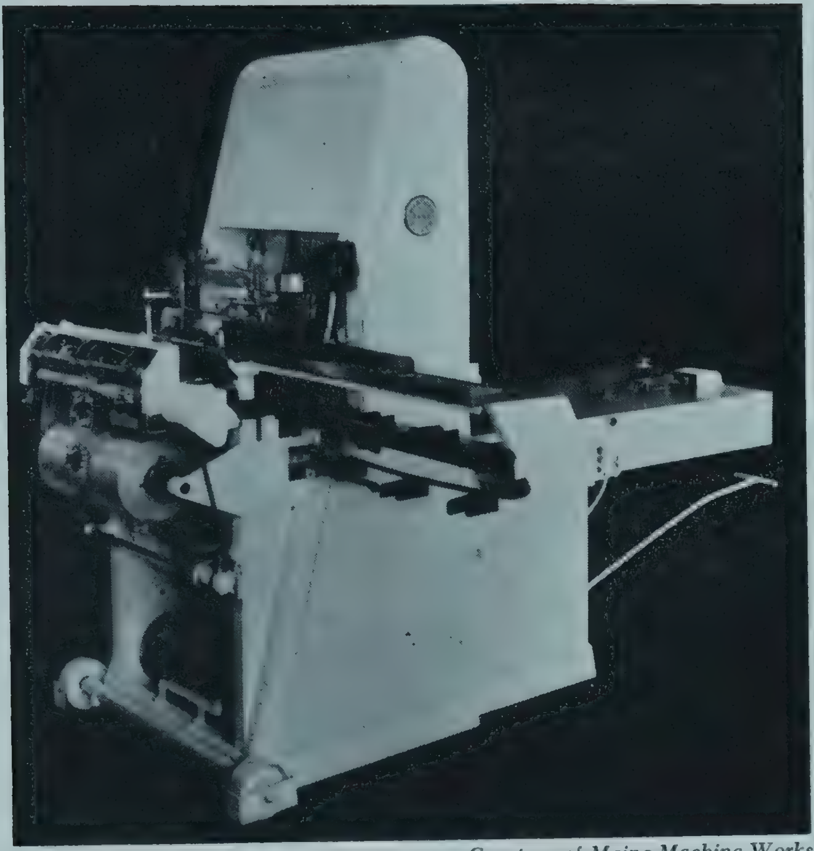
FIG. 178. ARRANGEMENT OF DRUMS AND BLADES IN A SLICER HAVING OFFSET DRUMS



Courtesy of American Machine and Foundry Co

FIG. 179. A CONTINUOUS BLADE SLICER USING OFFSET DRUMS

labor costs and material. In addition, the blades are more nearly parallel at the position where they cross, creating better cutting conditions. The disadvantage of the arrangement is that the machine becomes quite tall. However, unless an unusually restrictive head space situation exists, a height of eight feet or so should not create any major problem. The floor space is not increased appreciably and this is usually the critical factor.



Courtesy of Maine Machine Works

FIG. 180. A SLICER-WRAPPER FOR ROUND LOAVES ILLUSTRATING A NEARLY VERTICAL ALIGNMENT OF DRUM CENTERS

Some manufacturers have decreased slicer height while maintaining band length by placing the blades at an angle to the floor. An arrangement of this type is diagrammed in Fig. 178. A photo of a commercial device using offset drums is shown in Fig. 179, while a machine using almost vertically aligned cylinders is illustrated in Fig. 180. The chief operational difference between the two arrangements is that the vertical alignment permits an almost perpendicular approach of the blades to the loaf, resulting in the exerting of a constant force on the bread at all times. With the offset drums, the blades contact a corner of the bread first and the force on the loaf continually increases until the blade crossover point reaches the center of the loaf. In most practical situations, it is debatable whether any difference between the two treatments could be detected. Machines designed with the offset drums may have the product approach lane changed from the horizontal to an angle as the slicing zone is reached so that the blades are almost perpendicular to the line of travel of the product, even though they may be at a considerable angle to a perpendicular to the floor.

The knife speed in modern slicers is from 900 to 1,200 feet per minute. Hartman (1948) states that blades are capable of slicing 500,000 to 2,000,000 loaves of bread between resharpening periods. In most machines, thickness may be adjusted, e.g. within the range of $^3/_8$ to $^5/_8$ inches, by a simple hand wheel control which moves the blade guides farther apart or closer together.

The subject of blade sharpening has been well covered by Diehl and Hansen and will not be further discussed in this section except to mention that there exists a certain amount of disagreement among blade manufacturers regarding (1) the desirability of honing blades on the machine while slicing is being performed, and (2) the cutting surface involved in the slicing operation. In contrast to Diehl and Hansen, Simmons (1959) feels that the danger of bread contamination by metal particles and dirt is a sufficient reason for avoiding automatic honing. Simmons also states that cutting is a result of the action of the burr on the cutting surface and that efficient slicing cannot occur in the absence of this structure.

Circular Blade Slicers

Machines of this type are used for slicing small pieces (or clusters) such as hamburger buns or frankfurter rolls. They generally consist of two serrated-edge blades placed on a level and horizontal to the floor. They are separated by a short, and usually variable, distance so that a "hinge" can be left in the roll or cluster.

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CHAPTER 22

Floyd P. Graw
and Samuel A. Matz

Wrapping Machines and Materials

PACKAGING MATERIALS

The packaging films most often used for bakery products are waxed paper, foil, Cellophane, glassine, and polyethylene. Not so many years ago waxed paper was practically the only film used for bread packaging. It is still very much in evidence, but first Cellophane and then polyethylene took over some of the market. Each of these films has some desirable features and some disadvantages.

The requirements for an ideal packaging material for bakery products might be summarized as follows:

(1) It must protect the product from drying out during its normal storage life as a result of the loss of too much water vapor, and, conversely, must protect the product from gaining large amounts of moisture when the atmospheric conditions are unusually humid. The latter conditions are seldom observed in most parts of this country since the crumb of the usual commercial loaf does not attain equilibrium with the atmosphere until a relative humidity of well above 80 per cent is reached (at normal temperatures). If the film protects adequately against moisture vapor transmission, it can also be expected to protect the product well from adventitious dirt, dust, and other foreign particles and it will give some protection against mold spores, off-odors, etc.

(2) The package must contribute to the dimensional stability of the product. Since most bakery products are very susceptible to crushing, structural strength must be added by the wrapper if the product is to survive handling during storage, transport, and merchandising without distortion.

(3) The film must be capable of being easily and quickly applied by mechanical means, and preferably by existing machines. A fundamental requirement is that the material heat-seal readily. It must be susceptible to rapid manipulation by the wrapping device without cracking, tearing, or suffering permanent deformation.

(4) The package must assist in selling the product. For bread this usually means that the product must be capable of being squeezed so that the customer can assure himself of its softness. In cases where visibility of the product is important (and this is usually found to be true), trans-

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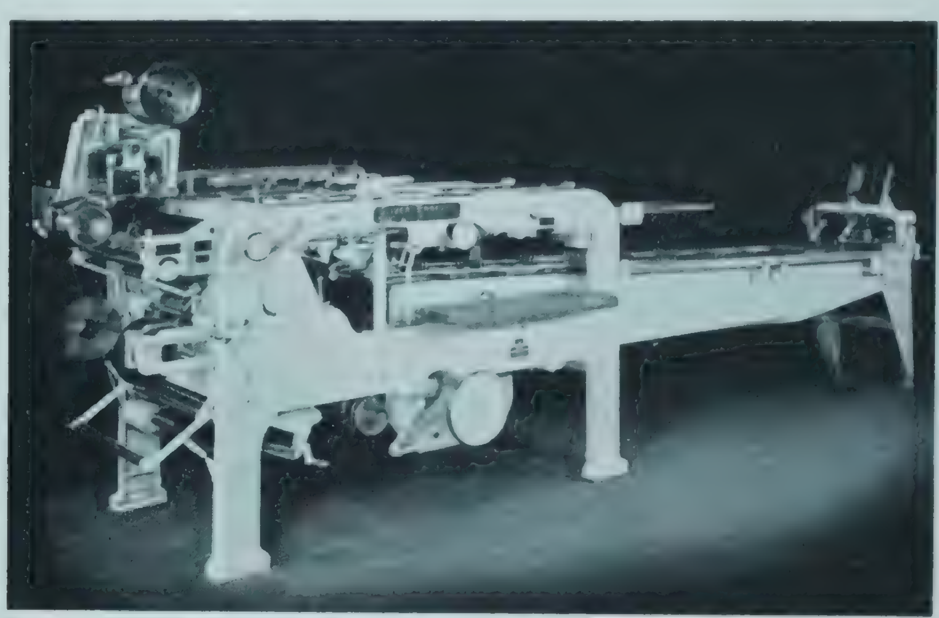
Floyd P. Graw is associated with Milprint, Inc.

parent films are imperative. Adaptability to printing is necessary in most instances.

(5) The film must be relatively low in price. It must have a low base cost and the supplier's factory or warehouse must be located so as to make transportation costs relatively low; it must be capable of being stored without loss and used without waste.



Courtesy of Oliver Machinery Co.

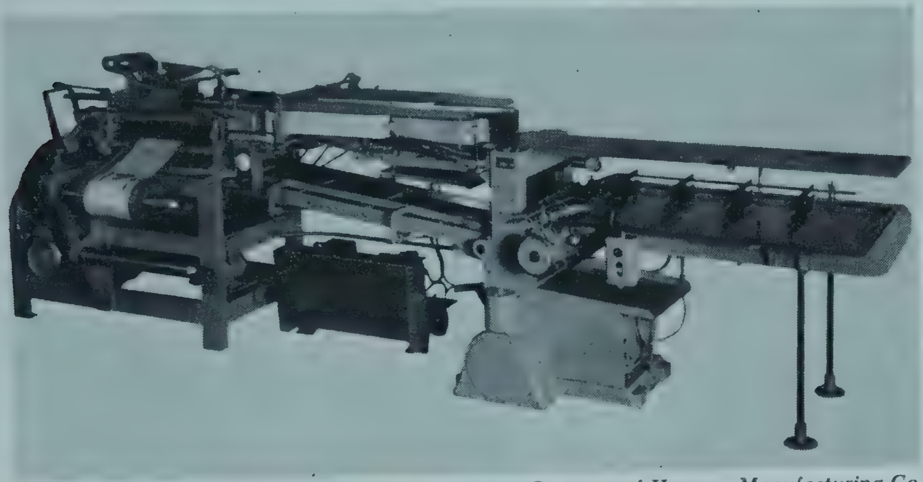
FIG. 181. OLIVER #790 STANDARD WRAPPING MACHINE

Few, if any, films possess all of these qualities in the desired degree. Shortcomings of one film may be compensated for by using combinations of materials. Thus, the lack of strength and rigidity in some transparent films can be overcome, at least partially, by using bands or trays of tougher materials. Laminations, particularly of aluminum foil, are another way of taking advantage of the best qualities of several materials in one film.

Greaseproof Paper and Glassine

These papers are not often employed for bread packaging although a few bakers use bags made of them for enclosing French bread and the like. Cookies, crackers, pastries, and brown 'n serve rolls are frequently packaged in greaseproof paper or glassine. Greaseproof paper is formed from cellulose fibers which have been digested for a relatively long time during the pulping process and consequently have a high moisture content. Glassine is prepared from greaseproof paper by a procedure which includes a supercalendering step. The application of heat and pressure in this step makes the fiber mat denser and more or less transparent. Greaseproof paper is similar in appearance to parchment, being opaque or translucent. The so-called manila glassines range from a deep to a very light amber in color, while bleached glassine is virtually colorless.

Neither glassine nor greaseproof paper offer much resistance to the transmission of water vapor. Of course, coatings to improve this characteristic can be applied. As indicated by the name of the basic product, the papers are quite resistant to the absorption and transfer of fatty materials. This property is attributable to the high degree of hydration of the cellulose fibers. Protection against the transmission of off-odors and off-flavors is said to be very good.



Courtesy of Hayssen Manufacturing Co.

FIG. 182. COMBINATION SLICING AND WRAPPING MACHINE

Greaseproof paper and glassine are not heat-sealable. Coatings of wax or lacquer can be applied to remedy this defect. The papers can be printed by the usual methods, except when coated. The basic papers are obtainable in a weight range of 20- to 45- (laminated) lbs. per ream as continuous rolls or sheets. The 45-lb. laminated sheet is more commonly used in the snack food industry than in the baking trade.

White Bakery Stock Paper

Bleached sulphite paper (usually 28 lb. basis) is used for bakery bags for both retail and wholesale operations, principally to package crisp crusted breads such as French or Italian. In the wholesale trade, an untreated paper is used for gluing into bag form on bag making machines. This paper has no heat sealing properties. In retail operation the material is treated with hot melt wax to retain freshness of product. This treatment is done on one side only and penetrates the rather porous paper.

Bleached sulphite paper can not be printed in bright and vivid colors due to the porosity. The chief advantages of bags made from this type of material are the rather low cost, the high breathing value, and its wide and traditional acceptance for certain types of breads when unwaxed, and its low cost, whiteness, and good quality retention characteristics when waxed.

Transparent Cellulose Films

When Cellophane was first offered to the baker, he found only a very few types available. Today he has many varieties of this type of film with a wide range of properties from which to choose. Table 79 gives the characteristics of some commercially available films and the trade designations used by the different manufacturers.

TABLE 79

COMPARABLE SYMBOLS FOR COMMONLY USED TRANSPARENT CELLULOSE FILMS[1]

Source "A"	Source "B"	Source "C"
PT	P-1	None
LST	DS	None
MST-51	MS-1	MST-51
MST-52	MS-2	MST-52
MST-53	MS-3	MST-53
MST-54	MS-4	MST-54
MSC-51 TANGO	CMS-1 TANGO	None
MSC TANGO	CMS	None
MSAT-82, -86	MSB-6	None
MSAT-83, -87	MSB-7	None
450-K-202	None	None

Meaning of Symbols:

"S" denotes heat sealable coatings
"P" denotes plain film, no coating, not heat sealable
"M" denotes moisture-proof qualities
"T" denotes transparent (clear)
"C" denotes color, can be tango, red, amber, etc.
"A" means anchored coatings used for frozen baked foods
"K" denotes vinylidene chloride coatings on cellophane

[1] Graw (1956).

The so-called PT films (plain transparent) were never of value to the baking industry because they would not heat seal and retained moisture vapor very poorly, contributing to rapid staling of the product. Coated films of certain types overcome these disadvantages and have been widely used for bakery food packaging. Coated films with yields of 19,500 to 21,500 sq. in. per lb. in 300 gauge thickness and of 14,500 sq. in. per lb. in 450 gauge thickness have been especially useful. Recently vinylidene coatings have been used, and they have generally proved to be of excellent value in that they increase the shelf life of bakery prod ucts by decreasing moisture loss. Originally this film was available only in a 450 gauge weight due to the coating process but it is now obtainable in a 300 gauge weight free of fish eyes or non-uniformities of coating.

Cellulose film has a grain direction resulting from the manufacturing process. It is weak across the grain and relatively strong in the other direction. In use it is run through the wrapping machines so that minimum stress is placed in the cross grain direction. This procedure provides a strong package. Weakness may result from loss of moisture vapor or pick up of moisture vapor by the film with resultant shrinkage of the product and stretching of the film. On lengthy unsupported products such as 12-, 13-, or 14-inch loaves of bread, the foregoing characteristics can cause trouble in the form of tearing or bursting. In carton overwraps or in bags few difficulties are observed from this source.

During very low humidity periods the film can lose part of the 5.7 to 6.0 per cent moisture content it needs to keep it reasonably limp and pliable. If this situation is coupled with a wrapping machine that has dull cut-off blades, fracturing of the film may become excessive.

Cellulose films accept printing inks readily and have an unexcelled transparency which adds to the attractiveness of the package contents. They are inexpensive and available in forms suitable for use in all types of package machinery. They will seal at a fairly wide range of temperatures, producing a continuous and indestructible seal.

TABLE 80

APPROXIMATE YIELD AND THICKNESS FACTORS FOR CELLULOSE FILMS[1]

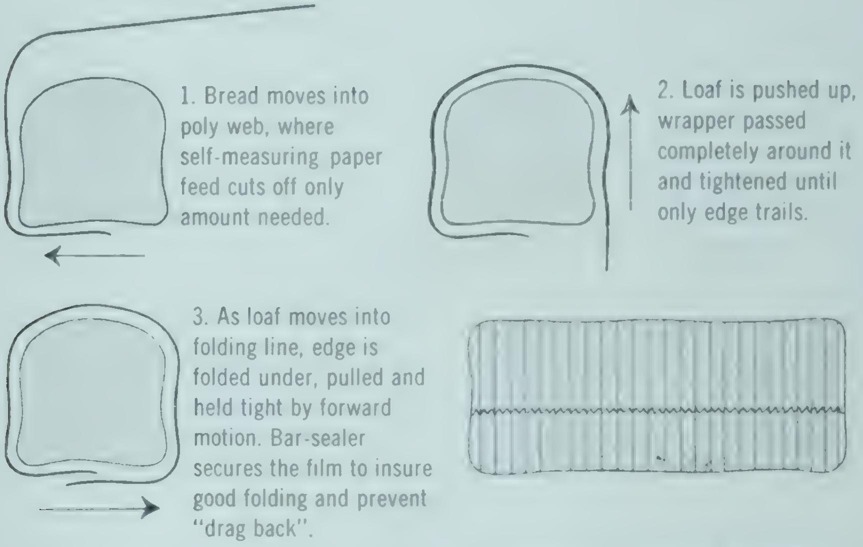
Gauge	Square Inches per Pound	Thickness, In.
	Plain Types	
No. 300	21,500	0.0009
No. 450	15,000	0.0013
No. 600	12,400	0.0016
	Moistureproof Types	
No. 300	19,500	0.0010
No. 450	14,000	0.0014
No. 600	11,600	0.0017

[1] Graw (1956).

Polyethylene Film

The films previously discussed are all derived from wood fibers. Polyethylene, however, is produced by heating ethylene, a gas, under high pressure in the presence of a catalyst. The physical characteristics of the product can be varied within a wide range by changing the reaction conditions. The first polyethylene offered to bakers was milky white in color and resulted in poor visibility of products packaged in it. Today there are available films which are transparent and have a soft very flexible texture that adds much appeal to the contents.

Polyethylene can be classified as either low, intermediate, or high density. In addition, there are linear types which have somewhat different qualities from the standard process material. The most common films for bakery use are three-quarter or one mil thick high-density polyethylene for wholesale bread and one and one-fourth mil for home service sales (Berkin 1959).



1. Bread moves into poly web, where self-measuring paper feed cuts off only amount needed.

2. Loaf is pushed up, wrapper passed completely around it and tightened until only edge trails.

3. As loaf moves into folding line, edge is folded under, pulled and held tight by forward motion. Bar-sealer secures the film to insure good folding and prevent "drag back".

Courtesy of Package Machinery Co.

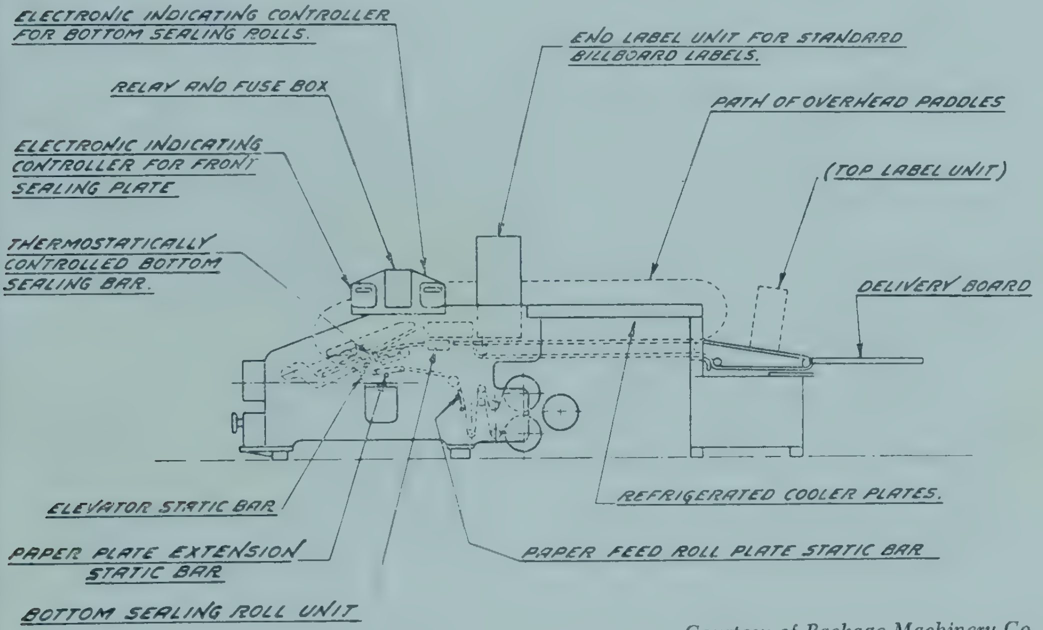
FIG. 183. SEQUENCE OF WRAPPING OPERATIONS

The moisture vapor transmission rate of polyethylene films is low, but the resistance to grease penetration is rather low. The untreated film reacts very poorly to ordinary printing techniques, but surface treatments to modify this defect are now being used. The lack of rigidity in the film creates some difficulties in feeding and handling in the wrapper, but these are not insuperable.

Heat-sealing of polyethylene is complicated by the narrow range of temperatures which give satisfactory results. This range is approximately 25 degrees over or under the correct temperature as compared to a 100 degree range for waxed paper and Cellophane. Below the lower limit a false seal is formed which will open under the slightest tension, and in some cases no seal at all will be formed. Above the upper limit of the sealing temperature range, actual melting of the film may occur with the formation of pinholes, puckering, or actual destruction.

Only within the last 3 or 4 years have there become available wrapping machines for handling roll stock polyethylene. The problem delaying the use of roll stock was the need for development of heat-sealing units which would not stick to the film. One method for solving the problem for standard machines has been the use of polyethylene films with waxed paper margins. The actual seal is formed on the waxed paper. Seals can also be made through paper end labels.

Saran and polypropylene are other plastics which have been used in very minor amounts for baked foods packaging.


ELECTRONIC INDICATING CONTROLLER FOR BOTTOM SEALING ROLLS.
END LABEL UNIT FOR STANDARD BILLBOARD LABELS.
RELAY AND FUSE BOX
PATH OF OVERHEAD PADDLES
ELECTRONIC INDICATING CONTROLLER FOR FRONT SEALING PLATE
(TOP LABEL UNIT)
THERMOSTATICALLY CONTROLLED BOTTOM SEALING BAR.
DELIVERY BOARD
REFRIGERATED COOLER PLATES.
ELEVATOR STATIC BAR
PAPER PLATE EXTENSION STATIC BAR
PAPER FEED ROLL PLATE STATIC BAR
BOTTOM SEALING ROLL UNIT

Courtesy of Package Machinery Co.

FIG. 184. RELATIVE POSITIONS OF THE FUNCTIONAL ELEMENTS OF A BREAD WRAPPING MACHINE

Foil Laminations

Laminated foils are not much used for bread wrapping except for some of the higher priced specialty loaves, but they have found a place as wrappers for other bakery products and may in time take over some of the market now held by waxed paper, Cellophane, and polyethylene. A suitable foil lamination is virtually impervious to moisture vapor and grease and can be quite attractive, though of course not transparent. Unsupported aluminum foil puckers and tears easily, and for this reason, as well as to obtain a seal, it must be laminated with other materials when it is to be used as a wrapping film.

A foil lamination which was probably the original one used for bread wrapping consisted of a combination of wax-foil-adhesive-sulfite paper-wax. Some users found that excess wax melted from the foil side and accumulated on the wrapping machine, necessitating frequent downtime for cleaning. Subsequently, a lamination of foil-wax-sulfite paper-wax-strikethrough tissue paper was offered. The tissue, being porous, allowed the hot wax to flow through it to make the seal. At the same time, the flow of wax was retarded sufficiently to prevent accumulation of the substance on the machine. A different approach to the problem resulted in the development of a film consisting of heat sealing transparent lacquer-foil-adhesive-sulfite paper-wax-tissue. This tissue was a resin impregnated paper. A line of pinhole perforations about one inch in width on each side of the web allowed sufficient wax to flow out on to the adjacent surfaces to accomplish sealing, usually with the aid of a thermoplastic coated end label to add structural strength to the end.

A fourth type of lamination consisted of layers of lacquer-foil-wet adhesive-sulfite paper-wax-tissue. In this combination, the lacquer was a heat sealing type. Since it has to be applied at a very high temperature to the foil and sulfite paper layers (the wax and tissue being mounted later) the latter must be cemented together by a high-melting wet adhesive rather than wax.

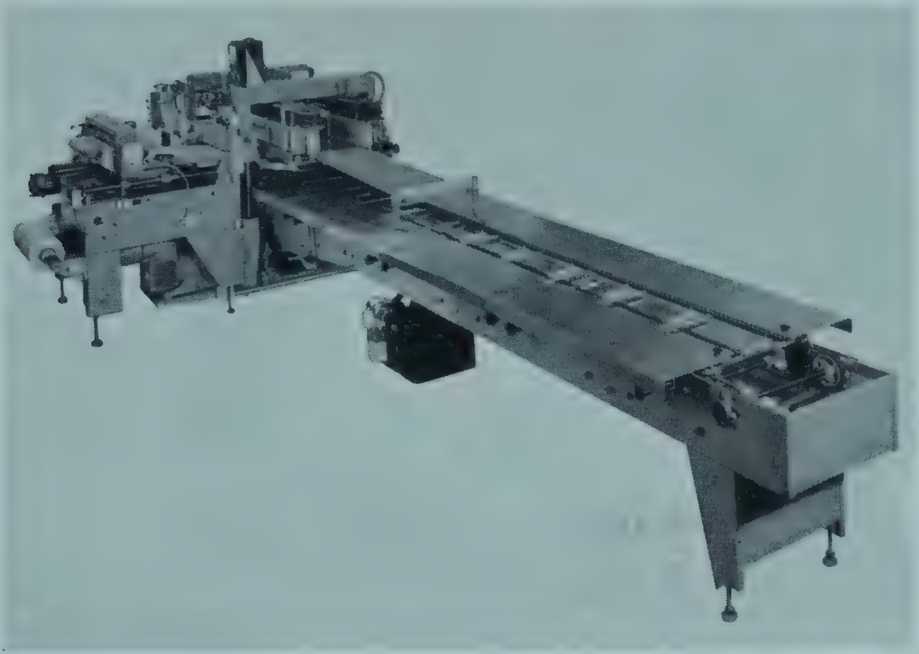
Recent technological advances have permitted the production of films coated with very thin layers of metal which have been deposited from the vapor state or by buffing with metallic dusts. These vacuum coated materials, usually called metallized papers, are being used extensively for candy packaging and have been suggested for use on bakery products. The principal advantage of these films lies in the added attractiveness which they contribute to the package. The metal layers do not contribute significant resistance to moisture vapor transmission as do foils.

PACKAGING MACHINERY

Bakery packaging machines deal with an unusually difficult group of products. Not only are the pieces varied in size and shape, but they are fragile and easily distorted. High volumes and low densities characterize some of them such as bread, and these qualities also contribute their share of problems to the designer of packaging machines. However, packaging engineers have met these challenges admirably by developing high speed wrapping machines which can successfully handle any of the baker's products. Some of these devices are too specialized to be discussed in any detail here. Instead, an attempt will be made to describe a few of the most important machines and some general principles of operation and maintenance.

The first operational element encountered by the product in a wrapping machine used for bread, for example, would be the conveyor mechanisms which transport the loaf from the slicer. Essentially, these are composed of flight plates supported and advanced by a pair of chain belts or link belts. Most wrapping machines can be obtained with a choice of several lengths of infeed conveyors. Lengths of 6, 9, 12, and 15 feet are commonly available. In some machines the slicer and wrapper are combined, eliminating the need for a separate conveying unit.

Sliced loaves are held together by stationary railings which may be arranged to compress the loaves slightly. Other designs have flexible plates which exert a slight pressure on the ends of the loaf to assure a tight wrap.



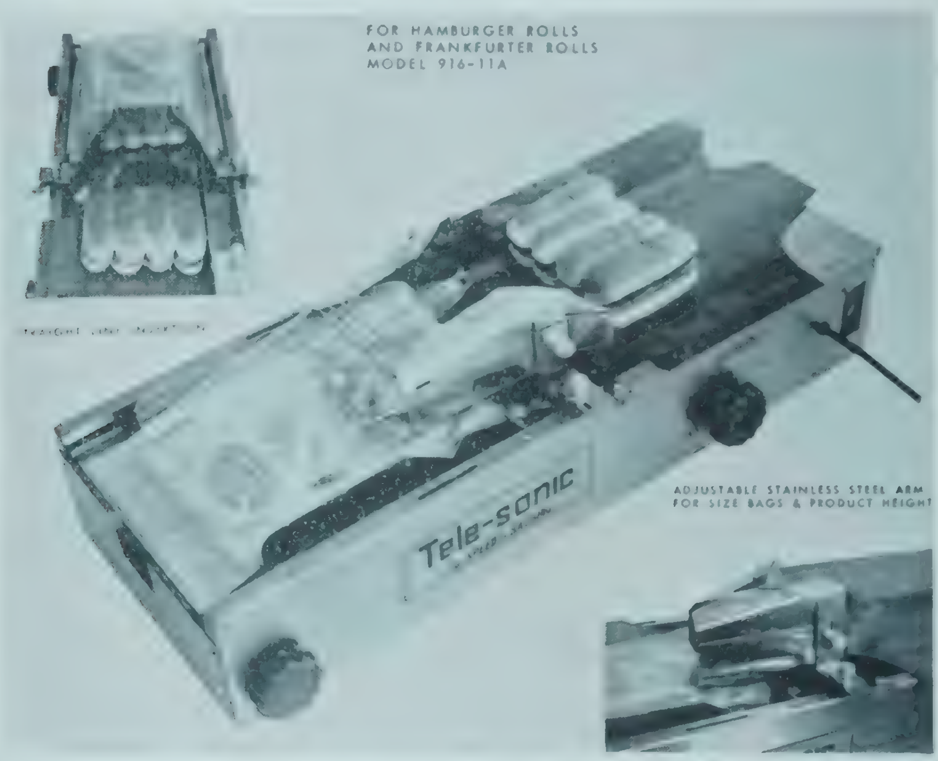
Courtesy of Oliver Machinery Co.

FIG. 185. OLIVER #879 POLYETHYLENE WRAPPING MACHINE FOR BREAD OR CLUSTER BUNS

The next functional element encountered by the product is the lifter table, or elevator, which receives it either directly from the infeed chains or as a result of the action of a pusher plate and arm. As the loaf advances on to the elevator, it moves into a pocket of packaging film which has been formed by retractable fingers. At this time the film is cut off to give a predetermined length. The elevator now lifts the loaf so that the paper or film is drawn across the top and passes down the trailing edge of the loaf. Subsequently, the direction of travel of the loaf is reversed and the loose edge of the paper drawn beneath it to contact the other cut edge.

Heat is applied along the line of contact of the edges to give the bottom seal. Fig. 183 illustrates this sequence of wrapping movements.

End folds are made by tuckers. One method of sealing involves making all four end folds and heating them simultaneously. This procedure has been largely supplanted by the progressive method in which each fold is sealed as it is made. Progressive sealing obviates the necessity for heat penetration through several layers of paper with the resultant danger of overheating and excessive wax (or other adhesive) flow. Neubauer (1953) says that the soft loaf is wrapped most effectively by using relatively high temperatures on the inner fold and relatively low temperatures on the sealer plates. Less wax is melted or burned off by this method. After sealing, the package may be brought in contact with cooling plates to solidify the wax or other adhesive and make the seal permanent. The cooling plates are usually refrigerated. Fig. 184 illustrates the relative position of the functional units in a bread wrapping machine.



Courtesy of Tele-Sonic Packaging Corp.

FIG. 186. TELE-SONIC MODEL 916-11A BAGGING MACHINE FOR LOAVES, CLUSTERS, PIES, ETC.

The heating and cooling plates, as well as other parts of the machine which come into contact with hot packaging material, may be coated with Teflon to eliminate sticking and the build up of carbon deposits.

If, as is frequently the case, an inner paper band is required, it is formed simultaneously with the wrapping operation and from roll stock. Top labels and similar inserts are deposited on the product as it enters the conveyor leading from the slicer. End labels, which can give valuable added strength to the end seal, are attached before the package reaches the cooling plates.

Wrapping speeds of 65 loaves per minute, and even more under very favorable circumstances, are possible with modern machines. The rate of packaging is governed to a large extent by the type of product and its size. As the dimensions increase, lower speeds are recommended. The rate must also be reduced when wrapping extremely soft loaves. In practice, the speed of the wrapping machine is determined by the output of the slicer.

The heat applied at the sealing plates is controlled by one or more thermostats. Most wrapping machine thermostats are of the "off-on" type and are adjustable within the range of 150° to 500°F. St. Arnaud (1959D) described a method for calibrating thermostats by using "Tempilsticks" and gave the following common causes of thermostat malfunctioning:

"(1) loose or broken heat-sensitive section (the part attached to the sealing plate); (2) leak in tubing or actuator, permitting gas or liquid to escape; (3) loose terminal posts; (4) faulty wiring; (5) loose connections on electric heating elements; and (6) burned out elements."

Preheated second folders improve the inner seals of heavy opaque material. Heated second folders or tuckers should not be used if Cellophane or synthetic coated papers are used as wrapping material. When second folders are to be heated, four-inch elements of 200-watt capacity are the proper size to use. In all cases, sealing plates should be heated by elements of equal size and a grooved element should not be paired with a smooth element.

The following points of preventive maintenance for wrappers should be emphasized:

(1) Do not allow carbon to accumulate on the sealing plate or folder surfaces. It will cause pits, retard heat transfer, and may pull out the end folds.

(2) Do not use bottom panels with badly worn ribbed surfaces. This condition can cause undue friction and crippling of loaves.

(3) Tuckers should be clean, free of marks, and of proper width. If a wider tip is desired on the end fold, file away the lower side of the tuckers up to the rear edge of the loaf until the desired result is obtained. Worn tuckers may cause first fold pull.

(4) Blow crumbs out of the finger assembly several times a day.

For assistance in troubleshooting, some of the common maladjustments and the types of defective packaging caused by them are summarized below:

(1) Off-center paper causes short folds at one end and bunching at the other, and the design will be off-center.

(2) Loaf pushers should be cut as specified by the machine manufacturer, which is the length of the loaf at the upper pan line. If shorter heels slip backward and the package end has a bad appearance, the end label will not center with the loaf and a weak seal will occur.

(3) Setting the machine too tight causes excessive loaf compression with resultant high pressure within the package. This may cause the ends to pop open when the chill plate pressure is released or cause a bad bottom seal.

(4) Setting the machine too loose decreases sealing strength, makes a sloppy looking package, and increases carbonizing.

(5) It is important to select the proper tuckers for the size of loaf being wrapped. Use of the wrong tucker blade reduces the chances for obtaining a good end fold.

(6) End label slippage may result from: (a) sealing plates too hot; (b) loose contact against the loaf end; (c) cold end label plunger; (d) sealing plates out of alignment; and (e) poor end folds.

(7) Bottom lap troubles may be due to: (a) slippage around the loaf; (b) loose tuckers; (c) tacky bridge plates and paper brake surface; (d) sticky chuck brake; (e) slow paper feed; or (f) worn lap roller assembly.

(8) If the bottom lap wrinkles, the machine is set too tight, slip-on plates are too short, or the sealer plates are not set correctly. Assuming that the tucker arms are not loose and the machine is properly adjusted, then the usual cause of bad folding is an excessively loose wrap.

(9) Paper tangling may result from a shear bar which has been bent (e.g. by cripples) enough to prevent proper cutting, or the variable paper drive may not be set correctly. The floating web stick should not climb to the top of the guide slots nor remain stationary at the bottom of the slots.

Some cluster buns are wrapped by machines similar to those used for packaging bread loaves (see Fig. 185). Simple bagging machines can also be used to package cluster buns and rolls (see Fig. 186).

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SECTION IV

Testing the Finished Product

CHAPTER 23

Gaston Dalby
and George Hill

Quality Testing of Bakery Products

Quality testing of bakery products produced and distributed by wholesale bakers represents the culmination of a number of quality control and process control procedures. The best quality in the finished product means that quality control of the ingredients has been properly maintained, the manufacturing processes checked, the wrapping and packing handled normally, and distribution carried out under usual procedures.

It is usually the best policy to obtain samples of the finished product directly from retail outlets. Such samples will be truly random and will have been through normal channels of distribution. The problem of distribution is a major factor affecting quality of bakery products, and it is therefore important to undertake quality control tests as nearly as possible on the actual products available to the consumer.

TEST PROCEDURES FOR DETERMINING INGREDIENTS

Moisture

The standard AOAC (Anon. 1955) procedure is followed for both bread and cake. In a loaf of bread moisture content varies widely from the crust to the center of the loaf. The end slices are much drier than the center slices. This is the reason why the official procedure calls for a moisture determination using either one half of the loaf or a whole loaf. This moisture variation also occurs in cake and is especially marked in pound cake. In a loaf of bread, the moisture content of the center core of the center slices is within a few tenths of one per cent of the moisture content of the dough from which the loaf was baked. This is true unless the bread has been permitted to dry out excessively.

Table 81 illustrates the moisture differential within a single slice of bread when it is fresh and when it is three days old.

It is an interesting speculation that this moisture shift may be associated with staling in some manner. It takes place concurrently with staling as does crumb hardening. When bread is frozen, staling does not take place; neither does moisture transfer. These statements of course assume a wrapper which is an adequate water vapor barrier.

Gaston Dalby is Director, and George Hill is Assistant Director, of Research and Development, Ward Baking Co.

Work in this laboratory has shown that the moisture transfer from one segment to another takes place in the vapor phase rather than in the liquid phase.

Moisture content is important in quality of product. This has been emphasized in bulletins issued by the American Institute of Baking (Anon. 1954B and 1959). It is also proved by the increasing emphasis on moisture-proofness of wrapping materials for bakery products.

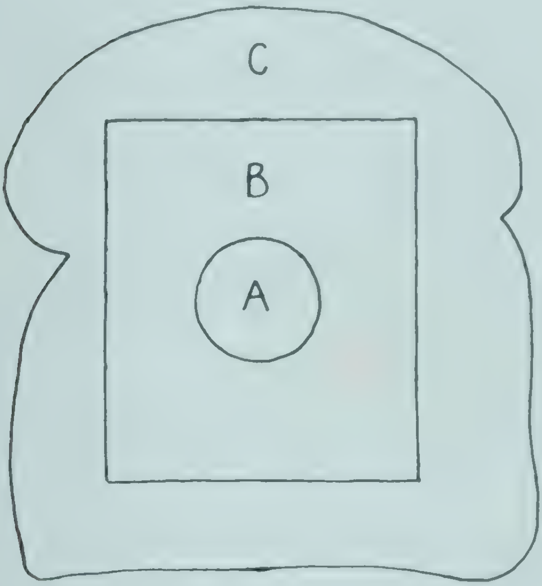


Fig. 187. Moisture Variations in Sections of a Bread Slice

In a typical fresh slice, section A might have 44 per cent moisture, section B 43 per cent moisture, and section C 32 per cent moisture.

Table 81

MOISTURE CONTENT OF VARIOUS SEGMENTS OF A BREAD SLICE, AND THE CHANGE IN THESE MOISTURE LEVELS AS THE LOAF STALES

	Fresh Loaf, Per cent	Three Day Old Loaf, Per cent
Center core	44.0	43.8
Intermediate area	43.0	40.9
Outside area	32.0	33.9
Entire loaf	37.0	37.0

It is often necessary to determine the moisture content of doughs and batters. One workable procedure is to take a weighed portion of batter or dough, 50 to 100 grams, add a measured quantity of water, and thoroughly disperse the dough or batter with the water in a Waring Blender. An aliquot is taken and total moisture determined by oven drying. The original moisture content of the dough or batter may then be calculated.

Fat

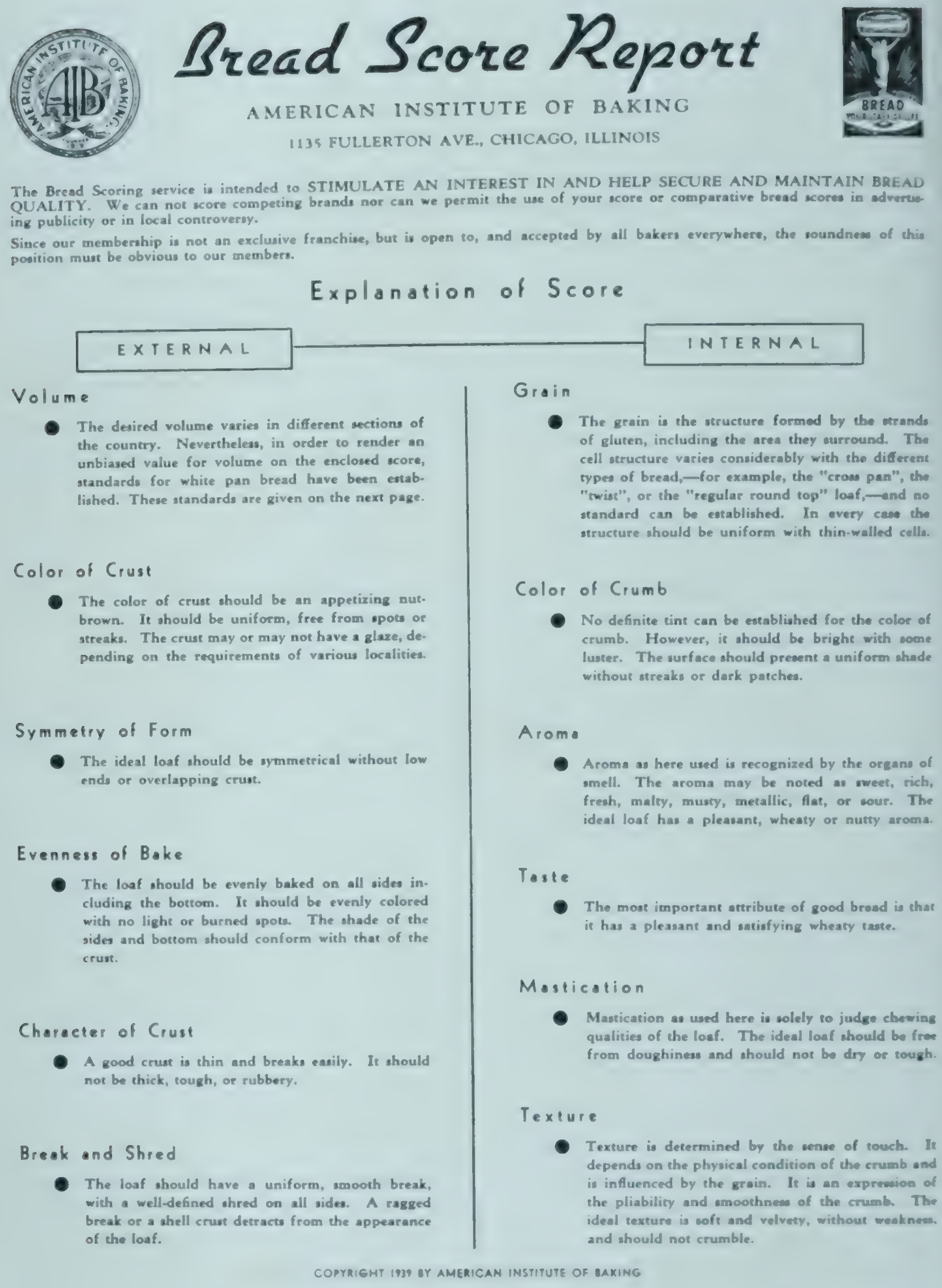
Fat content may be determined by standard procedures. In bread, total fat content consists of added fat and fat contributed by the ingredients, especially the flour. On the average, the fat content of a loaf of bread to which no fat has been added, will run 0.7 per cent to 1.0 per cent on the dry basis. In order to estimate the amount of fat added on the basis of the flour, this amount must be subtracted from the total percentage found also calculated to the dry basis.

The bread baker almost universally calculates added ingredients on the basis of the flour. If total fat is determined and calculated to the dry basis, and a correction made for fat contributed by the ingredients, the resultant figure on the dry basis is sufficiently close to the amount of fat added on the basis of the flour for all practical purposes. The reason for this convenient arithmetic is that flour usually contains 13 per cent to 14 per cent moisture. Other ingredients added to bread including fat, dry milk, sugar, salt, etc. approximate in total about 13 per cent to 14 per cent. Hence these ingredients in percentage are equivalent to the original water content of the flour, and a calculation to the dry basis will approximate the percentage based on the original flour. This same calculation may be used for milk, sugar, and other added ingredients.

If an analysis for butter fat is being made, then it is necessary to extract sufficient fat for a Reichert-Meissl number. If the percentage of butter fat in relation to total fat is low, then this becomes a very difficult determination to interpret.

The determination of total fat in cake is a straight-forward procedure but the interpretation presents difficulties. Besides shortening added to the cake, whole eggs or egg yolks contribute considerable amounts. Cocoa and chocolate also contribute fat. Iodine numbers, Reichert-Meissl numbers, melting point, etc. will help in identifying the source of the fat but each case is different. If the fat extraction is made for routine quality control on a product produced from a standard formula, then of course, the interpretation becomes easier.

The determination of monoglycerides in bread and cake is an unusually difficult problem and no adequate procedures are presently available. The fat must be extracted under mild conditions without hydrolysis in order to avoid the formation of monoglycerides from intact fat. The periodate titration procedure as developed by Pohle *et al.* (1945) and later studied collaboratively by a Committee of the American Oil Chemist's Society gives a presumptive estimation of monoglycerides in fat. Samples of bread baked with normal monoglyceride levels and other samples made with similar fat levels but without added monoglycerides will show similar



Bread Score Report

AMERICAN INSTITUTE OF BAKING

1135 FULLERTON AVE., CHICAGO, ILLINOIS

The Bread Scoring service is intended to STIMULATE AN INTEREST IN AND HELP SECURE AND MAINTAIN BREAD QUALITY. We can not score competing brands nor can we permit the use of your score or comparative bread scores in advertis ing publicity or in local controversy.

Since our membership is not an exclusive franchise, but is open to, and accepted by all bakers everywhere, the soundness of this position must be obvious to our members.

Explanation of Score

EXTERNAL

Volume

- The desired volume varies in different sections of the country. Nevertheless, in order to render an unbiased value for volume on the enclosed score, standards for white pan bread have been established. These standards are given on the next page.

Color of Crust

- The color of crust should be an appetizing nut-brown. It should be uniform, free from spots or streaks. The crust may or may not have a glaze, depending on the requirements of various localities.

Symmetry of Form

- The ideal loaf should be symmetrical without low ends or overlapping crust.

Evenness of Bake

- The loaf should be evenly baked on all sides including the bottom. It should be evenly colored with no light or burned spots. The shade of the sides and bottom should conform with that of the crust.

Character of Crust

- A good crust is thin and breaks easily. It should not be thick, tough, or rubbery.

Break and Shred

- The loaf should have a uniform, smooth break, with a well-defined shred on all sides. A ragged break or a shell crust detracts from the appearance of the loaf.

INTERNAL

Grain

- The grain is the structure formed by the strands of gluten, including the area they surround. The cell structure varies considerably with the different types of bread,—for example, the "cross pan", the "twist", or the "regular round top" loaf,—and no standard can be established. In every case the structure should be uniform with thin-walled cells.

Color of Crumb

- No definite tint can be established for the color of crumb. However, it should be bright with some luster. The surface should present a uniform shade without streaks or dark patches.

Aroma

- Aroma as here used is recognized by the organs of smell. The aroma may be noted as sweet, rich, fresh, malty, musty, metallic, flat, or sour. The ideal loaf has a pleasant, wheaty or nutty aroma.

Taste

- The most important attribute of good bread is that it has a pleasant and satisfying wheaty taste.

Mastication

- Mastication as used here is solely to judge chewing qualities of the loaf. The ideal loaf should be free from doughiness and should not be dry or tough.

Texture

- Texture is determined by the sense of touch. It depends on the physical condition of the crumb and is influenced by the grain. It is an expression of the pliability and smoothness of the crumb. The ideal texture is soft and velvety, without weakness. and should not crumble.

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Fig. 188. Bread Score Report as Used by the American Institute of Bakin
Page one

monoglyceride quantities in the extracted fat. It must be assumed that monoglyceride is formed during the fermentation and baking processes. This was reported by Dalby (1949) and exhaustively studied by Kuhrt *et al.* (1952). The extraction of monoglycerides from bread crumb under conditions sufficiently mild to prevent hydrolysis is a difficult procedure and this difficulty may in part be due to the possibility that there is a strong chemical bond between monoglycerides and starch and it is because of this affinity that monoglycerides exert their softening action on bread crumb.

Milk

The determination of milk in bread and cake may best be done by the lactose determination. The official procedures call for the extraction of the total sugar and the subsequent fermentation of all the sugar present in the extract except lactose. A simpler method than the official one as reported by Hoffman *et al.* (1936) gives excellent results for routine quality control determinations. Lactose occurs in non-fat milk solids at a level of 50 per cent approximately. Therefore the lactose percentage multiplied by a factor of two will give the percentage of non-fat milk solids.

Sugar

Total sugar in bakery products is determined by official procedures. The chemical analysis will show total reducing sugar. In bread this will generally be a combination of lactose, maltose, dextrose and fructose. If a lactose determination for milk is being made at the same time, the lactose can be deducted from the total. Usually total sugar minus lactose is all that is required for quality control procedures.

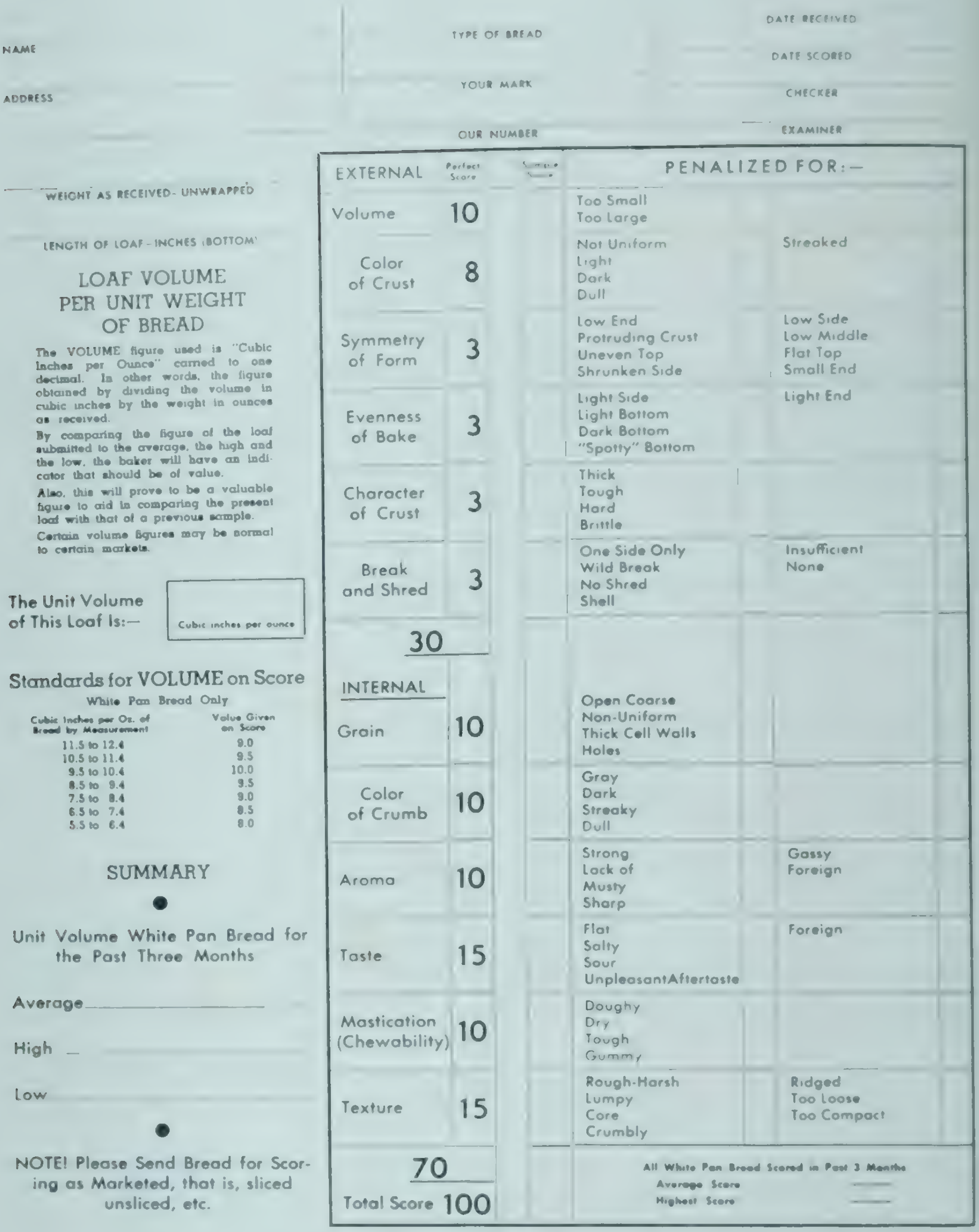
No sucrose can exist in yeast raised bread due to the rapid inverting action of the yeast enzymes. This action takes place so fast that sucrose cannot be found in a dough immediately after it is removed from the mixer.

The identity and approximate quantity of sugar in bread may be determined by chromatographic analysis.

Protein

Protein is determined by official procedures (Kjeldahl method). In products containing high fat levels, it is often helpful to remove part of the fat by washing with ether before digestion is started. This will help prevent excessive foaming when the final distillation is made.

For bakery products a factor of 6.25 for conversion of percentage nitrogen to protein is generally used. Although wheat protein requires a factor



NAME

ADDRESS

TYPE OF BREAD

YOUR MARK

OUR NUMBER

DATE RECEIVED

DATE SCORED

CHECKER

EXAMINER

WEIGHT AS RECEIVED- UNWRAPPED

LENGTH OF LOAF-INCHES (BOTTOM)

LOAF VOLUME PER UNIT WEIGHT OF BREAD

The VOLUME figure used is "Cubic Inches per Ounce" carried to one decimal. In other words, the figure obtained by dividing the volume in cubic inches by the weight in ounces as received.

By comparing the figure of the loaf submitted to the average, the high and the low, the baker will have an indicator that should be of value.

Also, this will prove to be a valuable figure to aid in comparing the present loaf with that of a previous sample.

Certain volume figures may be normal to certain markets.

The Unit Volume of This Loaf Is:— Cubic inches per ounce

Standards for VOLUME on Score

White Pan Bread Only

Cubic Inches per Oz. of Bread by Measurement	Value Given on Score
11.5 to 12.4	9.0
10.5 to 11.4	9.5
9.5 to 10.4	10.0
8.5 to 9.4	9.5
7.5 to 8.4	9.0
6.5 to 7.4	8.5
5.5 to 6.4	8.0

SUMMARY

●

Unit Volume White Pan Bread for the Past Three Months

Average

High

Low

●

NOTE! Please Send Bread for Scoring as Marketed, that is, sliced unsliced, etc.

EXTERNAL	Perfect Score	Sample Score	PENALIZED FOR:—	
Volume	10		Too Small Too Large	
Color of Crust	8		Not Uniform Light Dark Dull	Streaked
Symmetry of Form	3		Low End Protruding Crust Uneven Top Shrunken Side	Low Side Low Middle Flat Top Small End
Evenness of Bake	3		Light Side Light Bottom Dark Bottom "Spotty" Bottom	Light End
Character of Crust	3		Thick Tough Hard Brittle	
Break and Shred	3		One Side Only Wild Break No Shred Shell	Insufficient None
	30			
INTERNAL				
Grain	10		Open Coarse Non-Uniform Thick Cell Walls Holes	
Color of Crumb	10		Gray Dark Streaky Dull	
Aroma	10		Strong Lack of Musty Sharp	Gassy Foreign
Taste	15		Flat Salty Sour UnpleasantAftertaste	Foreign
Mastication (Chewability)	10		Doughy Dry Tough Gummy	
Texture	15		Rough-Harsh Lumpy Core Crumbly	Ridged Too Loose Too Compact
	70		All White Pan Bread Scored in Past 3 Months Average Score Highest Score	
Total Score	100			

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FIG. 189. BREAD SCORE REPORT AS USED BY THE AMERICAN INSTITUTE OF BAKING. PAGE TWO

of 5.7, milk protein has a factor of 6.38 and egg protein a factor of 6.25. The factor of 6.25 is used as an average and may tend to produce a slightly high protein result when used for white bread.

Mineral Residue

Ash is usually determined on air-dried ground samples. The main precaution is to use low ashing temperatures to avoid loss of sodium chloride. Total ash is not too important in quality control since it is a total of all mineral residues from the ingredients plus added minerals such as sodium chloride, dough conditioner salts, calcium and sodium propionate, etc.

Type of Flour

By careful examination, the grade of flour used in bread manufacture may be estimated by color and brightness of crumb. Short patent bread flours compared to standard and straight patents are lower in ash or mineral content. Total ash *per se* is of no importance in flour grade since most of the mineral matter in flour is potassium phosphate and potassium phosphate has no affect on bread quality in the amounts that would be contributed by the ash of the flour. Grade is determined by extraction; that is, the number of pounds of flour obtained from 100 lb. of wheat. Manganese occurs in the mineral matter of wheat and the evidence indicates that its percentage is constant from year to year and from one wheat growing region to another.

The manganese contribution to bread from ingredients other than flour is minute; hence a manganese determination on bread will give, within reasonable limits, a good estimate of the extraction percentage of the flour used to produce the bread. Manganese may be determined with great accuracy by a comparatively simple procedure as reported by Hoffman *et al.* (1943).

Often the question arises concerning whether or not whole wheat flour is present in a bread product. Crude fibre may also be determined. If the crude fibre content of the bread is at least 1.5 per cent, it may be assumed that whole wheat flour was used in the manufacture of this bread.

Mold Inhibitors

Official procedures are available for the determination of acetates and propionates in bakery products. An empirical procedure is available for rapid determination of propionates in bread and cake.

Procedure.—Sixty grams of cake or bread as received are weighed together with 6 gm. of Filter cel or an equivalent filtering aid. The mixture is placed in suspension in 600 ml. of water.

The extraction can be carried out in several ways. It was found most convenient to utilize a Waring Blendor. In this case the material is blended for 3 to 5 minutes and then poured into 300 ml. centrifuge cups for separation. An alternate method is to soak the material over a period of 2 to 3 hours with occasional stirring and subsequent separation by filtering or, preferably, by centrifuging.

Four hundred milliliters of the supernatant liquid or filtrate are then added to a distillation flask together with 4 ml. concentrated phosphoric acid and a few glass beads to help overcome bumping. The suspension is distilled and the distillate collected in 100 ml. fractions. The fractions are then titrated with 0.1 N sodium hydroxide.

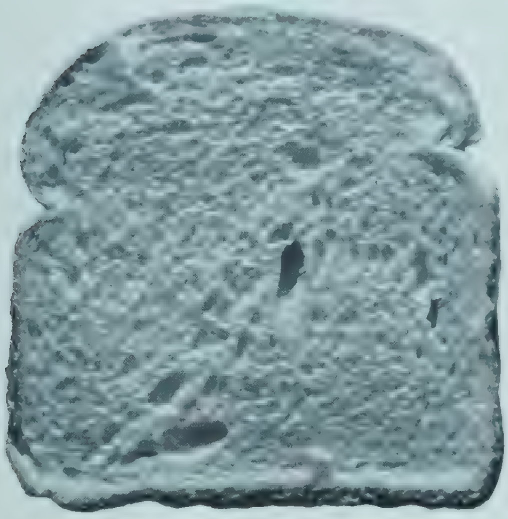


Fig. 190. Bread Slice Showing Very Poor Grain and Texture

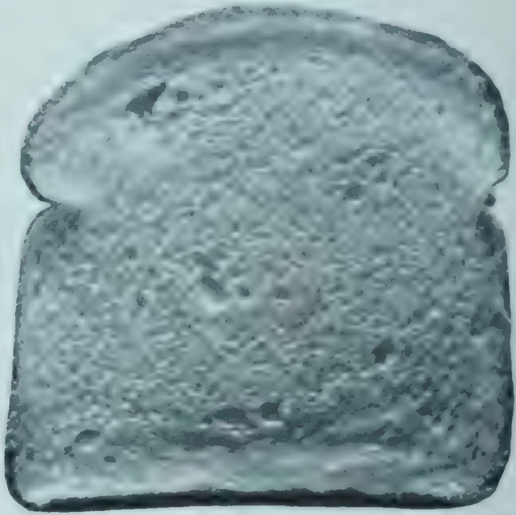


Fig. 191. Bread Slice Having Fair Quality Crumb Structure But with Some Holes, Irregular Cells, and Matted Cells at Bottom

A table similar to Table 82 is made up from a series of known propionate levels baked into test products, and the results of the three 100 ml. aliquot titrations are tabulated against a suitable factor such as oz. propionate per 100 lbs. flour, or oz. propionate per 100 lbs. total batter, etc.

Table 82

TITRATION VALUES OF 100 ML. ALIQUOTS FROM PROPIONATE DISTILLATION METHOD[1]

	1st Aliquot	2nd Aliquot	3rd Aliquot
No propionate	0.40	0.40	0.50
2.5 oz. per 100 lbs. flour	1.20	1.10	1.10
5.0 oz. per 100 lbs. flour	2.10	1.90	1.90

[1] These are typical figures for white bread but may vary under different conditions.

Since the blank may be as high as 20 to 30 per cent in low propionate level products a separate calibration curve for widely differing products is desirable.

VITAMIN AND MINERAL SUPPLEMENTS AS NUTRITIONAL FACTORS

Enriched white bread must conform to Federal Standards in order to be so labeled. Assurance of conformity to label statement is another function of quality control. In non-standardized bread and cake products vitamin and mineral assay is frequently necessary and always desirable not only for internal product control but also to supply nutritional data to interested medical and institutional groups as well as to individual consumers who are limited by dietary restrictions.

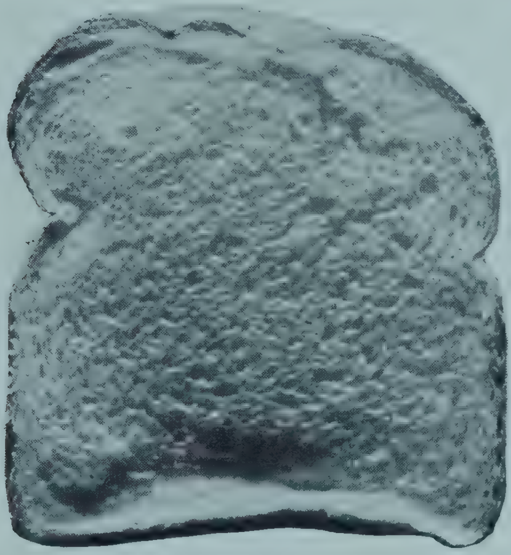


Fig. 192. Bread Slice with Grain of Generally Good Quality Even Though Uniformity of Cell Structure is Not Optimum

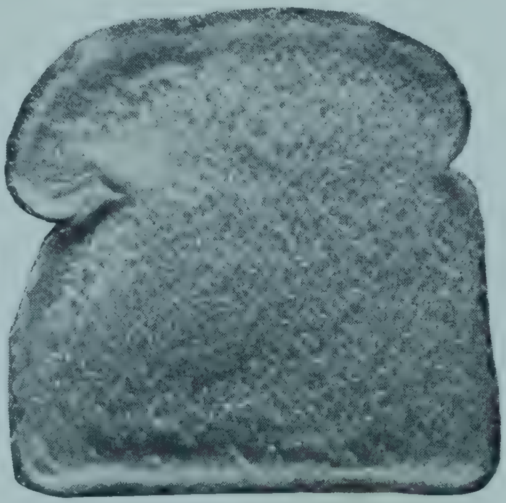


Fig. 193. Slice of Bread Having Excellent, Uniform Cell Structure

Standard enrichment factors for white bread include thiamin (B_1), riboflavin (B_2), niacin, and iron. The concentration of these nutrients in wheat is lowered in the milling of white flour, and to produce enriched bread, the baker usually adds enrichment wafers to his dough.

Thiamin, or vitamin B_1, may be assayed by a wide variety of methods including animal feeding, microbiological, and chemical. Animal tests are generally considered most significant since they are based upon biological response of a growth or curative nature. Their prime disadvantage is the time necessary to complete a test which varies from 3 to 8 weeks.

Complicating factors during that time frequently render the test quite variable with resultant difficulty of interpretation. The microbiological assays which depend upon growth and fermentation processes of bacteria, yeast and molds are somewhat faster, requiring from 4 hours to 2 or 3 days for completion. These procedures often result in higher assay values due to substances other than thiamin stimulating the test organism. They can, however, produce accurate values with competent interpretation.

The assay of thiamin by means of absorption spectra is a critical and effective approach but very limited in scope. Due to the high purity and freedom from interfering materials required by this technique, its principle value lies in the pharmaceutical field.

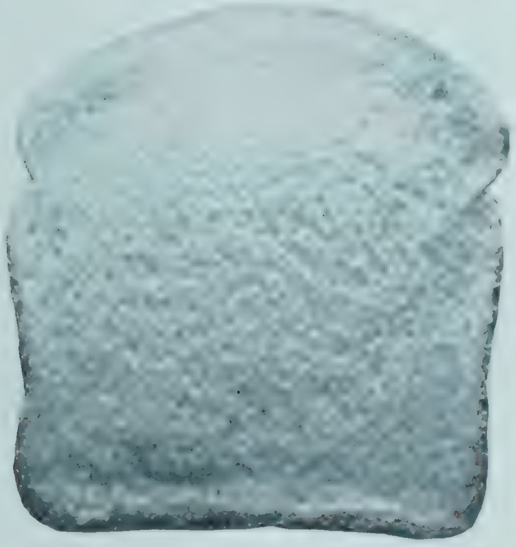


Fig. 194. Slice of Bread Having Excellent Cell Structure in All Respects

Chemical vitamin assay methods are becoming widespread in use, particularly in quality control work. Their greatest advantage is speed. Determinations made on a single type product, for example bread, can be turned out at the rate of about 20 per day per analyst. Critics of the chemical procedure hold the results to be less accurate than others and to suffer from poor inter-laboratory agreement. However, through the efforts of collaborative work among members of technical organizations, these difficulties are being gradually overcome. Bechtel and Hollenbeck (1958) have shown, in collaborative work involving eleven different laboratories, a coefficient of variation based upon single determination of as low as 2.9 per cent for some baked goods, and 8 to 13 per cent for products containing interfering pigments such as breakfast cereals. The chemical method most widely used involves extraction of the vitamin, usually with enzymes, separation of interfering materials, and finally oxidation to thiochrome whose fluorescence under ultraviolet light can be measured.

Riboflavin, vitamin B_2, is assayed in much the same manner as thiamin. Animal, microbiological and chemical methods are all widely used and each group of methods have about the same advantages and disadvantages as encountered with thiamin. Once again in quality control work, the chemical approach is most practical because of the time factor. The inherent difficulties of the assay, like those of vitamin B_1, have been and are continuing to be studied by collaborative groups with promising results.

In the determination of niacin microbiological and chemical methods are employed. The former utilizes the measurement of acid production during the growth of *Lactobacillus plantarum* while the official chemical method depends upon colorimetric measurement of a sulfanilic acid addition compound with a niacin derivative. Little can be added for this assay that has not already been pointed out in the cases of thiamin and riboflavin. Although the chemical method is to be preferred for speed and for the laboratory making infrequent assays, the microbiological approach is the more convenient for the organization dealing with a larger number of determinations and having facilities for the maintenance of proper bacterial cultures.

The assay of iron is a relatively simple, straightforward, chemico-optical method. The method with but slight variation is recognized by both the Association of Official Agricultural Chemists and the American Association of Cereal Chemists. It consists of ashing the baked product or original flour, dissolving the ash in acid, mild reduction to maintain the iron in the ferrous state and color generation with either 1, 1-dipyridyl or *o*-phenanthroline. The light transmission of the resulting solution is then determined at 520 millimicrons wave length by means of a spectrophotometer, neutral wedge photometer or similar instrument. A calibration curve is made from standard iron solution and the concentration of the unknown obtained from the curve. Differences between duplicate samples can usually be held down to 2 to 3 per cent variation in this procedure.

MICROBIOLOGICAL TESTING OF INGREDIENTS

In past years, one of the most serious problems confronting the baker during warm weather was "ropy" bread. This is a condition caused by spore forming bacteria which survive baking temperatures. The high alpha-amylase content of the bacteria cause severe degradation of starch; in some cases almost liquifying it, and other enzymes present in the bacteria develop objectionable odors. These so-called "rope" bacteria can occur in flour, yeast, and salt products. Modern processing conditions have practically eliminated this problem, but it formerly was a very important quality control consideration for flour, yeast, and malt. A satisfactory quality control procedure for rope spores was reported by Hoffman *et al.* (1937).

A number of cake ingredients are potential sources for microbiological contamination. Cocoa in recent years has become a serious source of bacterial contamination when it is used in icings and creams which are not subjected to heat. Cocoa also may often be very high in mold spore count. Coconut when used as a topping on cakes and not heated may be a source of mold and bacteria which will affect the quality of the cake.

Products which go into creams can be serious sources of bacterial contamination and if these creams are not heated in the manufacture of pies and pastries, there is the possibility of food poisoning. All types of frozen eggs may be the source of high bacterial contamination including staphylococci and salmonella. Dry egg white, dry whole eggs, and dry egg yolk can also be high in bacteria including toxin forming types.

Unexpected sources of bacterial contamination may be from solutions of egg color (usually solutions of coal tar dyes) which have shown coliform counts of 1.15×10^8. Vanilla solutions, usually diluted with water for bakery use, may show counts up in the millions. Topping mixes, prepared from milk solids and emulsified vegetable shortening may show extremely high counts of both coliform and staphylococci. The high bacteria counts existing in many ingredients that compose creams and fillings and which are not cooked, constitute a serious threat to public health. The extent of this threat is not fully understood because so many gastrointestinal illnesses cannot be traced to their cause. The quality control chemist has a great responsibility to his company in this area.

SCORING OF BAKERY PRODUCTS AND EFFECT OF PROCESSING VARIABLES ON FINISHED PRODUCT

The bread scoring system used by the American Institute of Baking is recognized as an excellent and well balanced system. This type of scoring system is especially applicable to a quality control laboratory that has to deal with many types of bread from different companies and various parts of the country. In an individual company with its bread standardized to the greatest extent possible, some of the scoring points are not necessary. The essential factors applicable for one company's quality control system can be worked out on simpler basis.

The American Institute of Baking scoring system for bread divides the factors to be considered into two categories: external and internal

External characteristics considered are: volume, color of crust, symmetry of form, evenness of bake, character of crust, and break and shred. Internal characteristics are grain, color of crumb, aroma, taste, mastication, and texture.

External Characteristics

Volume.—Bread volume is usually measured by displacement of poppy or mustard seed. The volume of the loaf in cubic inches divided by the weight in ounces gives the volume in terms of cubic inches per ounce. The standards used by the American Institute of Baking are as follows:

Cubic Inches per Oz.	Value Given on Score
11.5 to 12.4	9.0
10.5 to 11.4	9.5
9.5 to 10.4	10.0
8.5 to 9.4	9.5
7.5 to 8.4	9.0
6.5 to 7.4	8.5
5.5 to 6.4	8.0

The values given in this scoring system for white pan bread rate the average American pan bread as ten. Many special breads have a much lower cubic inch per ounce value, that is, they are denser or more compact. Volume is an important consideration in consumer acceptance. The importance that the housewife places on freshness as determined by the "squeeze" test has played a role in the increasing importance of volume in the last 25 years. The greater the volume or the lower the specific gravity of a loaf, the softer the loaf appears on the "squeeze" test. A consumer test made by the U. S. Department of Agriculture and reported by Bell (1956) showed that bread of 10 cubic inches per oz. was preferred over a loaf of 7 cubic inches per oz. Volume is, therefore, an important consideration in quality control.

Volume is affected by a great many factors both from the ingredients and from processing. The quality of the flour is extremely important in this respect. One of the basic criteria used in judging flour produced from experimental wheats is the volume of the loaf produced. Milk powder without proper heat treatment can produce bread with unusually small volume. The quantity of yeast used has an obvious effect on volume. In the sponge-dough process, the percentage of sponge and the time of sponge fermentation both affect volume. An increase in the percentage of sponge, assuming good quality flour, is one of the easiest methods of increasing volume. Other processing factors such as mixing and molding affect volume, but improper mixing and molding will affect internal characteristics as well as volume. Time and temperature of proof have an effect on volume as would be suspected since these factors are closely related to the overall fermentation development.

Color of Crust.—Crust color is a result of the development of caramelization during baking. The browning reaction due to an interaction of protein and reducing sugar also comes into play. Crust color is more affected by formula balance and oven conditions than it is by other factors. Milk solids and sugar tend to increase crust color. Old doughs in which much of the sugar has been lost by fermentation tend to lack proper crust color. It is obvious that a cool oven and too short a baking time will produce a pale crust color while too hot an oven and too long a baking time will produce too dark a crust color.

Symmetry of Form.—The usual defects listed under symmetry of form are small or low ends, shrunken sides, or protruding crust or "shelling."

Too stiff a dough due most often to too low absorption will produce a loaf with small ends. Inadequate fermentation and insufficient diastatic activity can also be contributing factors.

Shrunken sides develop during cooling and most commonly are due to insufficient baking. Too low a scaling weight in the pan is also a factor in the production of shrunken sides. This characteristic is sometimes referred to as "caving."

An excessively stiff dough, inadequate fermentation, and lack of proper diastatic activity are factors which contribute to shelling. The most common cause of shelling is, however, inadequate proofing due to a short time or too low a temperature in the proof box. Lack of humidity in the proof box which will develop a crusty top on the dough as it enters the oven will help cause shelling. Lack of moisture in the oven which will accelerate crust formation will also lead to shelling.

Evenness of Bake.—Evenness of bake is controlled by correct proofing and by oven conditions. Over proofing or under proofing, by the effect on loaf size, will affect evenness of bake. Correct balance of oven heat, and in modern ovens, correct use of agitators, will give the desired evenness of color on sides, top, and bottom of loaf. If 4 or 5 pans are strapped too close together, it is often difficult to obtain correct sidewall color. The distance between pans, therefore, becomes of more importance as the time of bake is shortened since it is important for the oven heat to penetrate in the space between the pans and start the sidewall formation quickly.

Character of Crust.—The character of the crust that best suits any given market area for the type of bread concerned must be established. The typical white bread crust should be thin and easily broken. It should not be thick, tough, or rubbery.

The formula determines the character of the crust to a considerable extent. Insufficient sugar, milk, or diastatic activity will tend to cause a thick crust since the lack of these ingredients will slow down the development of the desired crust color, and the longer baking time required will develop the thick crust. A tough and rubbery crust can be due to a low shortening level. During the restrictions of the Second World War, commercial bakers experienced considerable difficulty with tough crusts. This caused serious slicing problems in the bakery, and was due to a considerable extent to the low fat levels being used.

Proofing without sufficient humidity will develop a crust before the loaf goes into the oven. After baking, the crust will be too thick. Low oven temperatures will develop thick crusts since the baking time must be extended and hence the crust area dries out and becomes thick before the interior of the loaf is baked. Conversely, very high oven temperatures will also develop thick crusts since there is much crust formation before the interior is baked. Bread dough when proofed is an excellent insulating material and the penetration of heat is relatively slow. The oven temperature must therefore be selected to produce the desired rate of penetration of heat into the loaf without the undesirable crust formation. The increase of oven heat does not increase the rate of heat penetration into the loaf proportionally, but high heats dry the surface at a correspondingly higher rate.

Break and Shred.—When the fully proofed loaf enters the oven, heat penetration starts. Gases in the dough expand and yeast activity accelerates temporarily until the temperature reaches the thermal death point of yeast activity. This causes what is known as "oven spring," and develops "break and shred." The sudden rise exposes dough at the sides of the loaf, without any preliminary crust formation. If this is ragged and rough it is undesirable. The shell crust or "shelling" has been discussed under *Symmetry of Form*, but this condition is also related to *Break and Shred*.

If the oven spring occurs at a period in the oven after which inadequate time is available for some crust formation in the exposed break, then when the bread is wrapped, keyhole formation is apt to occur. This means that the top crust is pushed down and overlaps the side of the slice. This detracts very much from the slice appearance.

The desirable type of break and shred is related quite closely to flour quality, and is one criterion used in evaluating flours. Weak flour, or flour improperly aged will form poor breaks. The relation of proofing and baking to each other also affects this characteristic. Too little proof will lead to a large oven spring and consequently to an undesirable break and shred. A dry proof box and a dry oven will also affect this since these conditions cause crustiness before true crust formation occurs.

Internal Characteristics

The most important internal characteristic of a loaf of bread is the crumb structure. The terminology is somewhat confusing in this area. "Grain" should be defined as the actual cell structure of the loaf. A coarse grain is one in which the cells are large and the cell walls are thick. A fine silky grain is one in which the cells are small, elongated rather than round, and the cell walls are thin. The cell structure affects the color by its effect on light refraction. A coarse grained slice will appear darker in color and a fine grain slice whiter even though both loaves were made from identical ingredients.

Texture should be defined as the smoothness of the crumb and is not to be determined by visual inspection but by a sense of feel. A true texture determination in this sense is very subjective and is difficult to define and score exactly. It is closely associated with grain, and in many scoring systems there is a tendency to use the term "crumb structure" and "grain and texture" rather than attempt to measure both qualities individually.

The importance that the baker attaches to crumb structure is often puzzling to a person outside of the baking industry. It can be said that bread is to be eaten, not looked at, and therefore why should the baker be so concerned about the visual appearance of the crumb structure. The more nearly optimum the cell structure of the loaf, the better the eating qualities as affected by mouth feel, and the better the keeping properties. An older loaf with fine cell structure will have a fresher eating quality than a loaf actually fresher in period of time, but with a coarse cell structure.

The internal characteristics scored by the American Institute of Baking are as follows:

Grain.—Grain is affected by almost every ingredient and by almost every processing variable. The basic quality of the flour is of utmost importance in the production of fine grain. If milk is used, the product must be adequately heat treated. Improperly heat treated milk solids will develop a coarse cell structure in the loaf with dramatic effect. The type of shortening used will affect cell structure. In general, the lower melting point shortenings will tend to give a coarse cell structure whereas the higher melting fats will tend to produce a fine cell structure. Fermentation must be optimum. If a bakery is producing bread of coarse cell structure, a variation in fermentation time is one of the first approaches made to correct the condition. Mixing is also of very great importance. Both under mixing and over mixing will produce coarse grain. The molding stage is of equally great importance. Good molding may help offset some previous faults in processing. Correct baking conditions are important to produce good grain. Too cool an oven will permit too much rise in the oven and thus produce coarse cell structure. Too hot an oven, on the other hand, will "set" the loaf before correct oven spring takes place.

The experienced quality control chemist can make reasonably accurate deductions as to the cause of grain faults. If there are large holes present and other characteristics are normal, the fault is probably at the molding stage. If, in certain areas of the slice, there are matted cells, this may suggest poor quality or inadequate maturity of the flour. If the cells tend to be uniformly large, the mixing is probably too little or too much. This is an extremely complicated field, and requires a great deal of experience for one to give a correct explanation for a bread fault. Even to the experienced technician, it is often impossible to pinpoint the fault, and a trial and error procedure in the bakery must be undertaken.

Color of Crumb.—Crumb color is affected by the ingredients and by processing. The extraction of the flour, with other conditions equal, will affect the greyness or brightness of the crumb. Shorter extraction flour will give whiter and brighter crumb color and long extraction greyer and duller crumb color. Color is affected by the percentage extraction as distinct from the actual ash content of the flour. The creamy color of flour is usually removed by bleaching, and the difference in crumb color between bread made with bleached and unbleached flour is easily detected visually. Excessive malt, especially cereal malt, will develop a grey cast to the crumb.

Processing variations have a great deal of effect on crumb color. Streaky colored crumb is usually due to improper fermentation somewhere in the process. Mixing has an effect in that properly developed crumb has the most desirable color due to the light refraction from the cell walls. Improper time for the first proof, that is the proof before molding and panning, has more effect on color than is often realized. If the dough ball is permitted to expand too greatly before being molded, the punishment it receives on passing through the molder rollers is sufficiently great to damage the structure and to reflect this damage as a change in color.

Aroma.—In quality control, a check for aroma is usually made to insure the lack of any type of foreign or undesirable odor. Musty flour can produce a musty odor in the bread. Improperly refined shortening or rancid shortening will give a distinct aroma. Excessive fermentation or too high a temperature of fermentation easily leads to "gassy" odors. Foreign odors are easily picked up by delicately flavored bakery products. Cleaners and disinfectants are often the source of foreign odor pick-ups. Any such product containing pine oil odor or a creosote derivative is especially dangerous. Plastic materials used for shipping trays can lead to serious foreign odor problems if the plastic has not been thoroughly heated to remove the solvent odors.

Taste.—Taste is entirely a subjective measurement, and consequently scoring of taste factors must be done with great care. In general, in quality control, the technician is interested in being sure that no objectionable or foreign taste is present. The lack of salt will give a very flat taste. A sour taste can be developed from overfermented doughs. Foreign tastes can be contributed by absorption from disinfectants and insecticides as in the case of foreign odors. Solvents used in printing inks have been known to cause foreign tastes in bread.

Mastication.—Mastication refers to the "chewability" of the bread. The quality control technician will look for doughy, dry, tough, or gummy characteristics. Doughy crumb is usually the result of underbaking. Dry crumb may be due to too much bake-out, drying out through the wrapper, or staling. Tough crumb may indicate improper formula balance especially a low shortening or mono- and diglyceride level. A gummy crumb may be due to a high alpha amylase level from cereal malt or bacterial amylase. Fungal amylase has a thermal inactivation point too low to cause gumminess. Gumminess can also come from too high a monoglyceride level.

Texture.—Texture as used in this scoring system is determined by the sense of touch, and is affected by all of the variables which affect crumb structure. In this sense texture has a limited connotation. The meaning of texture in a broad sense refers to several qualities which affect the consumer acceptance of the bread, and therefore texture in its broad sense is discussed in another section of this chapter.

CAKE SCORING

The great variety of commercially produced cakes makes a single scoring system impossible to apply. Only general characteristics may be discussed, and the quality control technologist must establish the points he feels are important to his company.

As in bread, scoring points may be divided into external and internal.

External

The volume, or specific gravity, is of great importance, and the volume of any sample to be scored must be checked against the norm established for that variety.

The color of the crust is important. Thick, dark crusts are objectionable. Spotty crust of non-uniform color is objectionable to the eye. In layer cakes especially, the symmetry of form is important. The layers should be even and not have a high center, or be depressed in the center. The crust should not be blistery, tough, rubbery, or dry.

Internal

The crumb structure is important. The cells should be small with thin cell walls. Stratification, especially in pound cakes, is to be avoided.

Crumb color is an important scoring characteristic. If the cake is a yellow cake, the intensity of yellow color should be noted. Color is affected by crumb structure, and a fine crumb will give the appearance of a lighter color.

Aroma and taste should be checked with very careful consideration being given to foreign odors and tastes since cake is especially susceptible to absorption of foreign odors and tastes.

A determination of total moisture is important since this factor has considerable bearing on the shelf life of the product. The optimum moisture must be established for each type of cake.

Packaging

Packaging is especially important in cake products, and it is useful to record the type of wrapping material used as to whether, for example, it is regular Cellophane, polymer-coated Cellophane, or other types of wrapping material.

Icings and Creams

The stability of icings and creams is especially to be noted. Icing that dries out and becomes crumbly, or conversely icings that become sticky are undesirable. Creams may break down and become watery without proper stabilization. In warm weather, icings and creams must be watched for any possible development of bacterial spoilage.

LOSS OF INGREDIENTS AS A RESULT OF PROCESSING

The fermentation losses in bread processing are of considerable significance. In the sponge-dough process of bread manufacture the naturally occurring sugar in the flour (usually about one per cent) is lost rapidly. The yeast then must utilize maltose formed by enzymatic conversion of starch. Sugar is added at the time the dough is remixed, and some of this sugar is lost during the trough fermentation and the proofing period and even in the early stages of the oven. When the bread is baked, alcohol and carbon dioxide are lost and these products constitute the end products of the fermentation of sugar, either sucrose or dextrose, and maltose as derived from starch. If a reducing sugar determination is made on baked bread, it usually runs 2 to 2.5 per cent less than the percentage of sugar added at the dough stage. This figure is based on a total reducing sugar determination, excepting lactose, but including maltose.

The determination of actual solids lost by fermentation is a tedious procedure. It may be done in the laboratory by careful weighing of all ingredients of known solids content, the inclusion of any dusting flour pick-up, pan grease pick-up, etc., and the total solids of the original dough are calculated. All the dough is baked into bread, the bread is cooled, broken into fragments and dried. Total solids are determined and compared with the original total solids in the dough. Total loss of solids seldom runs under 5 per cent and often reaches 10.0 per cent. Perhaps 7.5 per cent is a typical average. The extent of this solids loss is not usually realized by the baker since it is included in the baking loss. At the baking stage the volatile ingredients formed by fermentation are removed.

Of the enrichment factors, thiamin is the only one affected to any extent by processing. The total baking loss of thiamin will average about ten per cent but this percentage figure varies according to the size of the loaf and the degree of baking. Thiamin is stable or only slightly affected in the core of the loaf, affected to a greater extent in the intermediate part between the core and the crust, and is most seriously affected in the crust areas. If the slice areas are divided into three parts as may be done for moisture determination in the various slice areas, it will be found that thiamin losses follow the same trend as baking loss of moisture.

A collaborative unpublished study among the baking laboratories in the New York area in 1950 showed the following:

	Mg. Thiamin Hydrochloride per Lb. Dry Basis
Core of loaf	2.19
Entire loaf	1.92

In addition to sugar loss by fermentation, starch loss by conversion to fermentable sugar and consequent fermentation, and loss of thiamin in baking, there is some loss in nutritive value of protein. Lysine is destroyed in the crust of bread to a limited extent. The entire protein may also be affected by browning reactions occurring in the crust areas. Baking losses due to protein inactivation as measured by rat growth tests suggest that the loss is in the area of ten per cent. It is the usual practice in preparing bread for animal tests to dry it to approximately seven per cent moisture and prepare crumbs. Crumbs are easily handled in formulation of diets. Unpublished evidence is presently available which indicates that further protein inactivation takes place in this drying stage, even though it is done at room temperature, and presumably is a result of reducing sugar reacting with protein or in other words, the browning reaction. This is an area in which much work might be done with profit to the baking industry.

The multiplication of yeast cells during a dough fermentation requires a source of nitrogen. One function of ammonium salts in dough conditioners is to furnish a readily available nitrogen supply. The growing yeast also attacks amino acids and lower polypeptides as shown by Baker (1957). These de-aminized products are an important source of bread flavor. Very important work in this field has been done by the American Institute of Baking and reported by Wiseblatt (1957). Whether or not amino acid de-aminization by yeast and reincorporation in the yeast cell is of nutritional significance to the finished bread is not known. The magnitude of this change is not large and therefore the nutritional significance is probably not of consequence.

FILTH TESTS AND THEIR INTERPRETATION

The Federal Food Drug and Cosmetic Act defines a food as adulterated if it consists in whole or in part of any filthy, putrid or decomposed substance or if it has been prepared, packed or held under unsanitary conditions where it may have become contaminated with filth. It is generally understood that the term filth here stated refers to contamination by insects or their fragments and to insect and rodent excreta. It certainly refers, in addition, to the more obvious types of inanimate foreign materials. The main concern here, however, is the former contamination.

In the baking industry the prime ingredient is flour and it is this ingredient that requires careful control of filth contamination. This control is not necessitated because flour is handled in any less sanitary way than other ingredients. In fact, flour handling in the mill and in the bakery has made rapid strides in recent years with respect to sanitation. The control is required by virtue of the bulk of material used and the fact that wheat and flour provide excellent harborage and food supplies for rodents and a relatively wide variety of insect life. Contamination can occur in the wheat field, in storage before and after milling, in transportation of the flour and in the bakery.

Ingredients, other than flour, can also introduce extraneous matter to the baker's products. Some of these materials, notably spices, are often high in insect fragment counts. Fortunately they are used at low levels in the finished product. The relatively high contamination level of this type product is almost entirely the result of conditions prevalent in the harvesting, drying, storage and shipment of the material. In addition to spices some degree of contamination may be introduced by cocoa and cocoa products, dried egg yolk, and dried fruits.

The methodology of determination of the nature and extent of filth contamination is as varied as the number of products in which the matter is found. Detailed descriptions of these procedures can be found in standard analytical texts such as the Official Methods of Analysis of the AOAC and Cereal Laboratory Methods. In addition Kurtz and Harris (1955) have compiled an extensive bibliography of various procedures studied during the period 1946–1954. In general the procedures involve digestion of the material by either enzyme or acid, flotation of the contaminants in mineral oil, castor oil, gasoline, etc., separation of the nonaqueous layer, trapping of the extraneous matter on filter paper and microscopic examination of the residue. Upon examination, a trained microscopist can frequently identify an insect from a small fragment.

Identification of a fragment, although not vital for routine gross counts, can be very useful in determining the origin of the contamination. If, for example, the majority of insect fragments in a flour sample are finely ground it is obvious the insects gained entrance before milling. It does not follow, however, that the contamination occurred in mill storage since it could also have occurred in the field. In their extensive reports on this subject Kurtz and Harris have pointed out that field contamination will usually be from the granary or rice weevils, the flat grain beetle, the sawtooth grain beetle and the lesser grain borer. On the other hand, contamination originating at the mill will more likely include the confused and rust red flour beetles or the Mediterranean and Indian meal moths.

The presence of whole insects or large fragments indicates that contamination originated after milling either in transportation or at the bakery. The presence or absence of live larvae or large larval fragments plus a knowledge of the life cycle of the insect can shed further light on the origin of the extraneous matter. In post milling contaminations the most likely trouble spots are areas in equipment where even a few grams of flour can be pocketed and by-passed by subsequent material flow. Sharp curves and crevices in enclosed flour handling and transportation systems, corners in sifting equipment, and flour dust build-up on machinery are examples of these trouble spots.

Insect and rodent excreta constitute another, and perhaps the most objectionable filth contaminant. The presence of such material is always indicative of a poor sanitary history of the product. Most common of the pests contributing fecal contamination in food products are the cockroach, mouse, and rat. Differentiation of roach and rodent feces cannot be made effectively on a basis of size. The rodent excreta, however, can be identified by the presence of characteristic hairs having a discontinuous medulla. There is some similarity between certain types of cat and rodent hair but the identification can almost always be made, certainly when the original feces are present. Conversely, the presence of rodent hair fragments in a digested sample prepared for analysis is very strong evidence of excreta in the original sample.

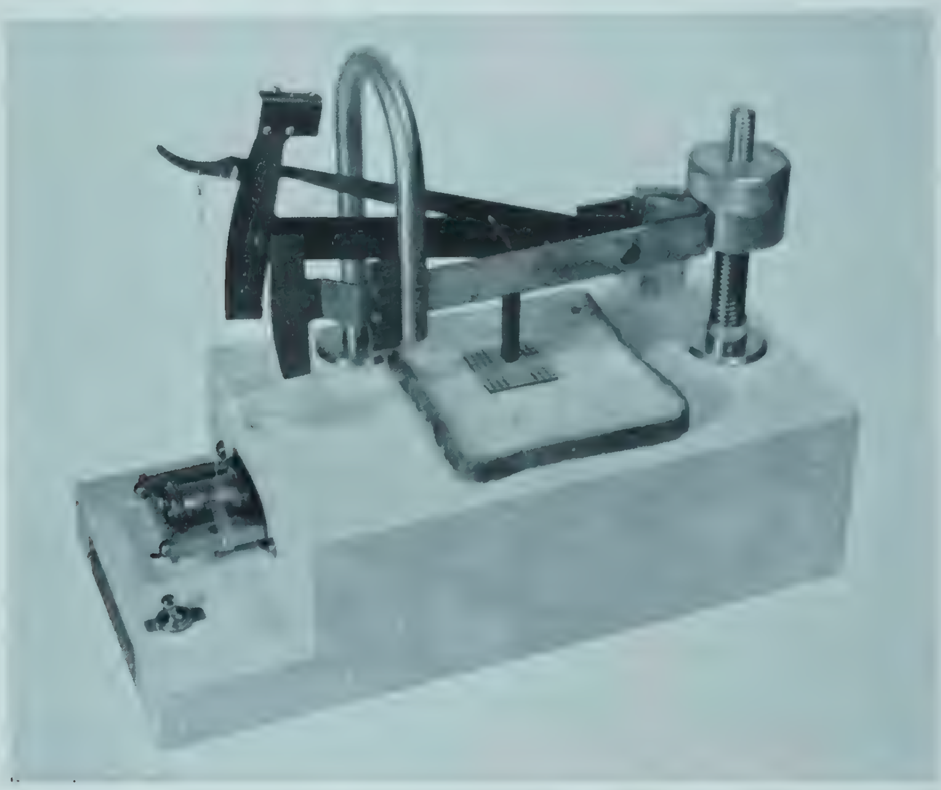
The incidence of rodent contamination in flour with today's effective packaging and total enclosed bulk handling systems is very low. The slight contamination that does exist is most probably pre-milling in occurrence. Other ingredients, and again particularly spices, still show significant levels of rodent contamination on occasion. Needless to say, this contamination can occur in or near the bakery or any food handling establishment unless very careful sanitation control is maintained.

TEXTURE—CONCEPT AND MEASUREMENT

In common bakery terminology, in the scoring rooms, and even in the responses of the consumer, the inference is almost always one of singularity when speaking of texture. This is certainly not the case. The term texture as related to bread is not an entity in itself but rather the accumulated affect of several characteristics. Appearance, feel to the touch, softness and, finally, mouth feel all contribute to the concept of texture in its broad sense.

Appearance is the first factor, at least chronologically, in the appreciation of bread texture. The size, shape and distribution of the cells are of prime importance. Ideally the cells should be comparatively small, slightly elongated or oval and evenly distributed over the surface of a well cut slice. Large cells produce an obvious coarseness to the eye while the pockets of shadow which they cause tends to impart a grey cast to the crumb color. If the larger pores tend to fall in any sort of ordered pattern the overall effect can be one of streakiness. This, of course, is also true of highly compacted cell areas resulting from improper molding, excessive or improper use of dusting flour and other similar processing defects. Some of the newer continuous type baking processes produce a cell structure which, in terms of uniformity, approaches perfection. Whether or not this degree of uniformity is to be desired can be argued. The resultant texture is almost cake-like in appearance. Although pleasing to the eye this structure has a note of artificiality in bread in much the same way that a machine made ceramic suffers a loss of charm and appeal which is inherent in the hand-tooled object. This is a factor which is related to the public's conception of what bread should be.

In a more practical and less esthetic sense the appearance of the crumb can yield important quality control information. The presence of significant numbers of over sized cells or holes points to poor fermentation and mixing control, or low quality gluten with insufficient mixing tolerance. An overmixed flour will result in weak cell walls which, under the pressure of fermentation, will break down allowing the formation of larger cells. Too, the effect is frequently the result of old doughs or excessive proofing. The nature of the cell walls as well as the cellular size is significant. Heavy walls, which contribute to coarseness, occur when the gluten is not developed to the optimum extent or when fermentation is subnormal as in young doughs. On the other hand, over mixing, long fermentation or gluten of poor quality will result in very thin cell walls



Courtesy of Wallace and Tiernan Co.

Fig. 195. Baker Compressimeter

which detract markedly from the characteristic appearance of a well made loaf. Well-processed loaves will produce a crumb character which is not only pleasing to the eye but soft, silky and inviting to the touch.

Softness, or yield of the crumb, must be considered an important part of bread texture. Certainly, in commercial bread production, as much emphasis is placed upon the development and retention of a soft crumb as upon any other single characteristic. The mono- and diglycerides of naturally occurring fatty acids such as stearic, oleic and palmitic are extremely important in softness retention. These materials are capable of significantly extending the time during which the bread remains acceptable to the consumer from a softness viewpoint. This is vital since softness is the texture factor most readily appreciated by the consumer and the only one detectable in the unopened package. Consequently, it affects point of purchase consumer acceptance. When the housewife squeezes the packaged loaf it must respond with a definite softness and yet possess the resiliency to gradually return to its normal shape. Incidentally, the nature and condition of the packaging material contributes markedly to the apparent texture qualities at this point.

Once the loaf is accepted and opened, the softness of each slice, particularly in the longitudinal direction of the loaf, becomes the dominant texture factor. Here again the crumb must demonstrate yielding softness without permanent distortion. Mellowed, well distributed gluten lattices and uniform cellular pattern will usually accomplish this end. As the bread ages the crumb is subject to deterioration of its softness qualities. Firming begins with concurrent onset of crumbliness. These physical changes, generally attributed in large part to the retrogradation of starch to a crystalline structure, are not preventable by the baker. His only recourse is to retard them by a balance of formula and careful attention to processing techniques. Assuming the bread is produced under optimum fermentation, make-up and baking conditions from good quality raw materials the rate of deterioration of softness qualities can be reduced by incorporation of emulsifiers and amylolytic enzymes, cooling and wrapping procedures which will maintain 37 to 38 per cent moisture levels in the delivered bread, and avoidance of chilling temperatures during handling and distribution of the finished loaves.

Finally texture involves the mouth feel, or bite tenderness, of the sliced bread. In this factor the crust shares equal importance with the crumb. A leathery or dried out crust will seriously detract from the tactile qualities of the bread on eating. These effects result in large measure from erratic or improperly controlled migration of free water from the core to the crust and between the crust and the atmosphere.

The crumb, instead of being tender and short, may display the undesirable characteristics of firmness and crumbliness, due to normal staling processes, premature dryness because of inadequate moisture protection, or gumminess frequently resulting from poor processing or excessive and improper use of enzyme additives. All of these factors are important in maintaining continued consumer preference for a particular product.

Objective Measurement

The nature of texture as defined here is highly complex. It is not a function of any one variable constituent or physical property. Complete objective measurement is, then, almost impossible. Fortunately we can follow and detect changes in softness and crumbliness with some degree of accuracy. Since these factors are those most readily discernible by the consumer, their measurement is a valuable tool in quality control.

The most prevalent measurement of crumb softness is based upon the principle of compression under controlled load. There are two instruments in widespread use for this purpose; the Baker Compressimeter and a modification of the Precision Universal Penetrometer originally designed for asphalt and grease testing.

The Baker instrument is a compound lever device reading in terms of both stress and strain. Each of these forces is independently variable and capable of being held in any position. Force is applied by a motor through the lever system to a coil spring and thence to the test piece by means of a plunger. Either the deformation of the bread under constant load or the load required to cause a constant deformation may be measured.

The Penetrometer is simpler in principle. It consists essentially of a vertical shaft, attached to a plunger, on which various dead weight loads can be placed. A dial gauge reads vertical movement of the shaft in tenths of a millimeter. Although the instrument can be adapted to determine constant deformation under variable load it is much more suitable for detecting amount of deformation under constant load. The conical plunger used on the instrument in asphalt work is replaced by one with a flat contact surface.

The relative merits of the instruments and methods used in determining crumb softness have been the subject of many reports. Plungers have been used in both round and square patterns. Samples have ranged from thick, hand cut, full size slices to prisms smaller than the plunger's dimensions. Determinations have been made with both constant load and constant deformation. Sliced samples, especially machine cut, have the advantage of being convenient and uniform and to some extent of providing enough space to make more than one reading per sample. The prism samples, however, eliminate extraneous forces such as shear and tension at the contact area, particularly when the sample size does not exceed that of the plunger. The technique of measurement has been extensively studied by Bice and Geddes (1949), Crossland and Favor (1950), and others. These workers found in the fixed deformation method advantages of increased accuracy and significance of data. While this technique is more practical with the versatile Baker instrument than with the Penetrometer, the latter has the advantage of mechanical and operational simplicity. When used with a constant load procedure the two instruments are in good agreement. Thompson and Meisner (1950) found a correlation between them with a deviation of only 1.3 per cent.

Neither system of softness measurement gives an exact comparison with the "squeeze" test used by the housewife. The wrapper has an appreciable effect on the "squeeze" test. If the loaf is thin sliced, it will give a softer "squeeze" test than a loaf with thicker slices. The thickness and character of the crust is measured by the "squeeze" test but often does not affect the softness determination by a compressimeter. A number of machines have been made and are in use at present which simulate to various degrees the housewife's "squeeze" test, but this developmental work is now in an active stage and no definite results are available.

Sensory Tests

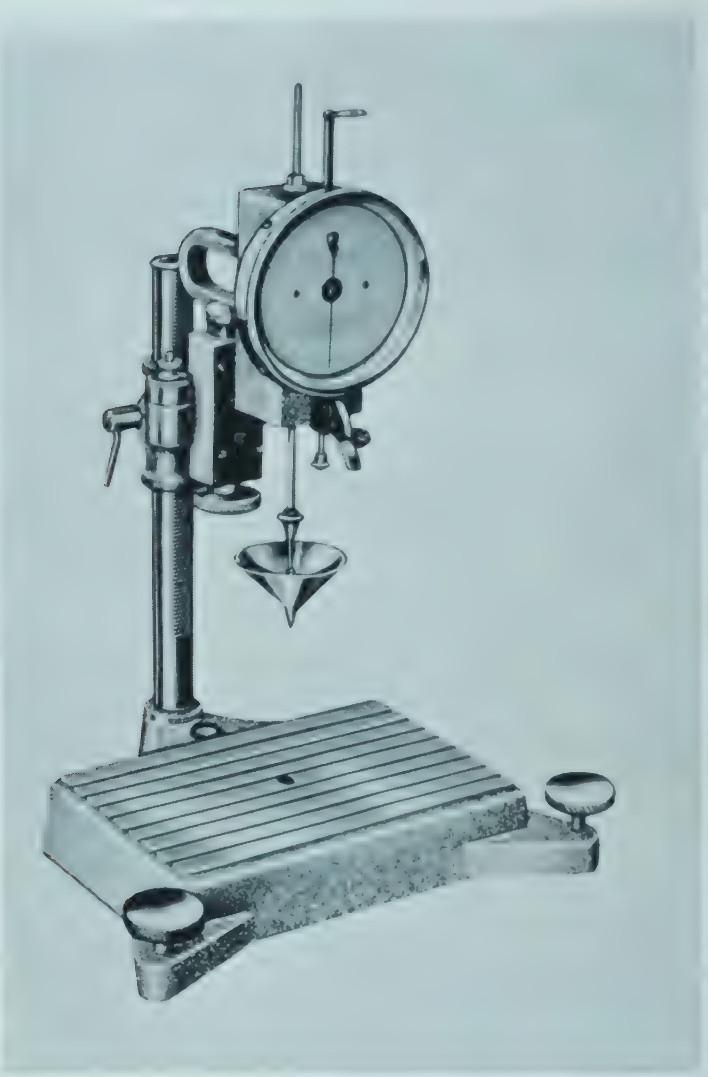
Sensory or organoleptic testing is of importance in any quality control program. In the scoring of bread and cake the taste and aroma are important rating points. In addition, the technician must always be alert for any type of foreign odor or taste. A sensory test is a personal reaction and a single judgment can be markedly affected by the subject's well being at the time of the test. Environmental conditions often affect the sensitivity of the test. The opinion of one person, no matter how expert, is not statistically projectable because of the subjective nature of the test. A panel test becomes important, therefore, when any change in formula and processing is involved.

A small expert panel is of value in testing a formula variation or perhaps a change in type of flavoring material. If a product has consumer acceptance it is important that any change in flavor be so slight as not to change its characteristics. The expert panel can determine, with reasonable accuracy, whether or not the change can be detected. If it is felt that the change is an improvement, it should always be checked by a consumer panel of some type.

In industry four methods of expert panel testing have been used. These may be summarized as follows:

Single Stimulus.—The problem is for the subject to distinguish between Sample A and B. Sample A is presented several times in succession. Then Sample A and B are presented, each singly, and in random order. The subject is asked to judge whether any test sample was *A* or *not-A*. Since a score of 50 per cent can be attributed to chance, the final score must be significantly above 50 per cent to indicate a definitive choice. Pfaffmann (1935) reports that the single stimulus method has been found to be very efficient for simple discrimination tests.

Paired Stimulus.—Sample A and B are to be tested. The following combinations are presented to the subject in random order: AA, AB, BA, and BB. The response is whether the samples are similar or different. In this test also a score of 50 per cent correct can be attributed to chance.



Courtesy of Precision Scientific Co.

FIG. 196. PRECISION COMPRESSIMETER

Duo-Trio.—Three samples are presented simultaneously. The subject tests them in left to right order and reports whether the second or third was like the first. The four possible combinations, ABA, AAB, BAB, and BBA are tested in random order. A score of 50 per cent may be due to chance. A variation is to present the subject with two different samples. After testing he is then given a third which is the same as one of the two already tested. The subject then identifies the third sample as either No. 1 or No. 2. In this variation, also, a score of 50 per cent may be attributed to chance.

Triangle.—This method differs from the Duo-Trio in two respects. The subject tests the samples in any order and is asked to report the odd sample which might be in any of the three positions. In this test, a score of $33^1/_3$ per cent may be attributed to chance.

The triangle procedure has become the most generally accepted of these procedures. This type of testing has a greater sensitivity when the dimension to be identified can be specified. If, for example, two vanilla flavors are being checked in cake, the subjects are asked first to select the stronger of the two flavors. With this specific dimension identified, a more accurate and meaningful selection can be made. The strength levels of the two flavors may then be adjusted and a second triangle test made with the subjects being asked to select on the basis of quality or character of flavor.

PANEL TESTING

A panel test is also important as a preliminary procedure for large scale consumer testing. This is illustrated in the report by Bell (1956). Twenty-four white bread formulas were developed by the American Institute of Baking in conjunction with the Bakery Research Council of the Department of Agriculture. Obviously, a consumer test using 24 different samples would be unwieldy. A panel screening test was established to determine the significant difference between these 24 formulas. From this group of 24 formulas, seven were selected by the screening panel as being mutually discriminable. Since seven formulas, however, were too many for a consumer perference panel, five were selected for the first consumer test.

Consumer Panel Testing

Consumer panel testing is perhaps the most important procedure in a research program developed to test consumer acceptance and at the same time is one of the most difficult methods to formulate and evaluate. The expert panel is of the utmost value to the food industry, but the preference of such a panel must frequently be audited by a statistical check with consumer sampling.

The methods of consumer panel testing may be divided into two general types: Mass panel survey, and household responses. A mass survey is usually conducted at some large public gathering such as a fair, or in a series of supermarkets. Paired samples are presented in random order to the participants. A score card is usually given with the samples. Such testing is more rapid, allows for better control of variables, and is less costly per individual test than household consumer testing. The criticisms of mass testing are that the subject is usually in a hurry, the environmental conditions bear no relation to the usual conditions under which food is consumed, and at mealtime other foods are eaten at the same time as the test foods.

Valdes and Roessler (1956) point out that in household consumer testing it is important to avoid conditions which force an immediate and hasty decision. The question of whether the subject should test two products or only one is an extremely difficult one to evaluate. With a single product under consideration, the test becomes a memory comparison based on previous experience, but, on the other hand, such is the real world. One seldom buys two similar products of different brands and makes a comparison test in the home. When two products are test paired there is a tendency to magnify differences which may not be of any real significance.

Consumer panels may be selected at random from those willing to participate in a specified area. Even this willingness to participate can inject an element of bias into the test. The income levels, the educational standing, and the racial type of the panel is selected with the type of market that the product may be expected to reach. A luxury product would not be tested in an area of low incomes. In the previously described report by Bell, 300 households were chosen in Rockford, Illinois, by selecting three households in every block through 100 blocks. Five different bread formulas were under test. One-fifth of the households received one of the five breads each week. The tests ran for five consecutive weeks so that each household would have experience with all five breads. The sixth week each household received the same bread as it had received the first week for the purpose of checking the reliability of the testing procedure. An interview was conducted with the homemaker in each panel household. The respondents were instructed to make a hedonic rating when they first tasted or ate the bread and to eat the bread plain befor arriving at their conclusions. This hedonic rating scale was furnished for each test bread rated from "Like extremely" to "Dislike extremely." In addition to the rating scale, total consumption was determined by counting the slices of bread not used during the test. Any bread not used for eating purposes was not included in the consumption figures.

Of the five breads under test, three received the same preference rating during the sixth week as during the first week of the test. This was a very good reproducibility of the preferences. Two breads, however, received significantly higher preference rating in the sixth week than in the first week. The authors stated "The conclusion to be drawn here is that, after the first week, experience with the other breads through the remaining four-week test period influenced opinion about these two breads so as to elevate preferences for them."

This consumer test conducted by the Department of Agriculture with the assistance of the American Institute of Baking and the Bakery Research Council is one of the most comprehensive ever made. The findings indicated the following:

"(1) Increasing the specific volume of bread from 7 to 10 cubic inches per ounce, making a lighter, fluffier bread, resulted in a significant increase in preference for the bread.
(2) Increasing the sucrose content from 2 to 7 per cent resulted in a significant increase in preference.
(3) Inclusion of four per cent of nonfat milk solids increased the preference for the bread significantly as compared with bread containing no milk solids; but a further increase in content to eight per cent did not have a significant effect.
(4) Increasing the lard content from 3 to 5 per cent did not significantly affect preferences.
(5) The pattern of preference for the experimental breads was not related to the socio-economic characteristics of the respondents."

This study illustrates an interesting sequence of events. The formula variations were selected by a committee representing most major baking companies. The 24 formulas were subjected to an expert panel for the purpose of selecting which of the formulas had significant differences among them. Then these formulas were tested by a household consumer panel to determine preferences. The expert panel had not been asked to give actual preferences; only differences.

Pangborn *et al.* (1958) reported on a comparison of mass panel tests, a laboratory panel test, and household panel tests in two geographical areas. This is one of the few comprehensive tests which compare all three types of panels. The problem was consumer response to sugar and citric acid levels in canned cling peaches. When judged by mass survey techniques, the three samples under test were almost equally well liked. At the household level, the California panel and the midwestern panel demonstrated a significant preference for the high sugar and high citric acid sample. The laboratory panel reference did not predict either the results of the mass consumer panel or the household panels. This result, although it did not involve bakery products, is illustrative of the complexity of the consumer testing problem.

Many large food companies maintain permanent consumer test panels. Households are selected by geographical location, income scale, and other pertinent factors. Often there is a waiting list of households who wish to join. Paired samples are sent to the households for testing. Responses are usually excellent since the subjects do receive free gifts of food products. This type of testing is subject to the desire of the respondent to please and not to be too critical of the products under test. Some students of this type of test feel that new blood must be injected constantly into the group even more rapidly than the normal mortality rate due to change of residence and other factors. Newer members of the panel have been shown to be more critical and more constructive with their suggestions.

Another function of a consumer panel is the "positioning" of a new product. For example a baker might consider a new type of bread. This could be distributed to a household panel with the request that the respondents reply as to whether the bread was used for toast, sandwiches, or for regular use at meals untoasted. If, for example, most of the bread was being used for toast, then the formulation of the product for the production of the best possible toast would be made. Hence this new type of bread would be "positioned" as a product for toast for breakfast.

Bakery products with their limited shelflife are more difficult to subject to a household consumer panel than other types of products which are less perishable. A development pattern for new products, or for a significant change in an old product, normally would follow the course of expert panel testing, a small household consumer panel which would furnish significant criticism on flavor, packaging, and keeping qualities, and then a market test in a selected area. The market test is a straightforward merchandising program. No paired testing is involved. A good product may fail its first market test due to pricing, packaging, poor advertising and merchandising, but usually some indication of where the fault is can be determined.

Sensory testing is one of the most complex elements in quality control. Developments in the field are constantly being introduced. *Flavor Research and Food Acceptance* (Anon. 1958) and *Food Acceptance Testing Methodology* (Anon. 1954A) are excellent sources for information in this difficult field.

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CHAPTER 24

James M. Doty

The Bakery Laboratory

INTRODUCTION

Many questions arise when a bakery considers the advisability of installing a laboratory. When is a laboratory warranted? What size should the laboratory be for a bakery or bakeries? What report forms should be used and how should reports be interpreted? What is the relationship of laboratory to production, to the sales department, to management? What commercial laboratories, routine and research, are available? What are the personnel requirements?

Successful laboratories are operating with one man and with one hundred men; therefore the requirements of the bakery are one factor, and the amount of money that can be allocated to the laboratory each month is another factor.

For a laboratory to produce its best results, capable personnel are necessary. Competent men are both scarce and costly. For this reason, laboratory monthly costs must be calculated realistically with an exploration of the definite salary requirements of capable personnel.

WHEN IS A LABORATORY NECESSARY?

A laboratory is necessary whenever a bakery has sufficient testing to be done to warrant the cost involved. This can be determined by learning the cost for the required number of tests from a moderately priced commercial laboratory. If the tests cost more per month than the cost of operating a bakery laboratory, then a bakery laboratory is warranted.

In calculating costs, it is vital that the number of tests per man hour be calculated expertly and accurately. Costs must be calculated by an experienced laboratory technologist. Management must recognize that a two-man laboratory can turn out more work in 40 hours than a one-man laboratory can turn out in 80 hours. A one-man laboratory lacks flexibility in scheduling work.

A bakery laboratory should include a laboratory bake shop. The day a one-man laboratory bakes bread by the sponge method, no other tests can be performed, since the baking tests require the full attention of an operator for the entire day. Therefore, if baking of five or more samples is required daily, no other tests may be made in a one-man laboratory

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One man can make 10 to 15 farinograph curves a day. However, if he tries to work in other analytical tests, his output will be reduced materially. This is pointed out to make sure that management will realize that practical scheduling of time is as important in the laboratory as it is in production.

Too often the cost of equipment and space for the laboratory are carefully considered, while the number of tests required and the personnel to run these tests are not so carefully considered. In trying to determine whether or not a laboratory is warranted, the capacity required should be the first consideration. When the capacity is determined, an expert should be called in to figure personnel requirements for this capacity. After personnel requirements are carefully established, determining the size of the laboratory is a simple matter.

Whenever a bakery laboratory is set up for routine analytical work, enough personnel should be included to allow for research and development. If the number of personnel is based on the requirements for routine work, no time will remain for research. Management often makes the mistake of feeling there will always be times when laboratory personnel can work on research and new product development. This mistake results in frustration later when management finds there is never enough time in the laboratory for research projects.

ROUTINE TESTS ESSENTIAL IN BAKING

Tests required fall into three classifications. First in importance is ingredient testing. Second is finished products testing. Third is testing of new products offered by suppliers to the baking industry. Details of research procedures or testing programs will not be considered in this section.

The tests necessary in a bakery laboratory will vary depending on the type of products manufactured. A bakery devoted to the production of cookies and crackers would require a different testing program than a bakery devoted to yeast-raised products. Likewise, a cake bakery would have a different set of tests than those required in a pretzel bakery.

Ingredients to be tested and the common tests essential to maintain uniformity of products should be carefully considered. Unnecessary tests should be avoided, yet all essential tests should be run regularly on all incoming shipments of ingredients. The laboratory should be equally vigilant and careful in testing the finished products produced in the plant.

To check properly flour for a yeast-raised bakery, the laboratory should check flour specifications and the baking performance of the flour. Bread flour is sold on protein, ash, maltose or some other amylase test, and in most cases with a farinograph specification. Furthermore there are federal limitations on moisture. Therefore to check flour the laboratory should be set up to run protein, ash, moisture, amylase, farinograph curves, and baking tests.

To test flour for the cake, cookie, and cracker bakery, a laboratory should also check flour specifications and the baking performance of the flour. Soft wheat flours are sold on protein, ash, moisture, viscosity, pH, and, occasionally, on farinograph specifications. Therefore, these routine tests should be set up in a laboratory checking flours for this industry. In addition, specialized baking equipment, constant temperature storage cabinets, incubation cabinets, and storage cabinets for packaged finished products should be added.

In the modern bakery, milk is used in both yeast leavened and chemically leavened products. Therefore, provision should be made for routine testing of milk products. The important tests on milk are moisture, acidity, total fat, and occasionally bacteria count and total sugars. Very few modern bakeries use liquid milk; however, if they do, then equipment for determining total solids in milk should be included in the laboratory plan.

There are many types of shortenings used in the baking industry. It may be necessary to include some fat and oil testing equipment. In yeast-leavened products, the lard or shortening should be checked for free fatty acids and stability. These two tests are important to the cake baker as well, although rancidity of fats and oils may be less important because of the masking effect of flavoring materials used in cakes. The cake baker needs information on emulsifiers, melting points, and on occasion, the iodine number and the stability of fats.

In the cake baking industry, eggs are a very important ingredient and the laboratory should be equipped for certain routine egg tests. Whether the eggs are fresh, frozen, or dried, a few basic tests should be performed by the cake bakery laboratory. Fresh and frozen eggs should be checked routinely for total solids, bacteria count, and shell fragments. Dried egg yolks and frozen yolks should be tested for total sugar. Equipment for total fat determinations could be used for testing both yolks and whites of eggs. A special beater for the mixer can be purchased which could be used in running beating tests on egg whites to determine volume and weeping character.

Syrups and molasses should be checked routinely. Hydrometers can be used to determine the brix value of both syrups and molasses. On occasion syrups should be checked for total sugar chemically. This requires no special equipment. Syrup ash is often a good index of quality, particularly in molasses type syrups.

Chocolate and cocoa products can be checked for total fats in the cake bakery laboratory. The fat test will serve as a guide to maintain quality and uniformity in all good standard chocolate and cocoa products.

For economic reasons, it is not always wise for a laboratory to include equipment for tests that are run only occasionally. The investment for such equipment is not warranted, and the laboratory personnel will have difficulty in fitting occasional tests into routine operations. Tests that can be run more economically by a commercial laboratory will save both dollars and man hours. For this reason, no provision has been made for vitamin assay, caloric value, lubricating and fuel oil testing, water analysis, etc. The tests outlined are the bare essentials for routine testing. In the preceding chapter, testing procedures for determining quality and uniformity of finished bakery products were outlined.

FITTING THE LABORATORY TO THE NEED

The most difficult evaluation to make in setting up a laboratory is the determination of what is adequate, but not too elaborate. It is better to under-equip than to over-equip. Additional equipment can be added as needed. On the other hand, more laboratory floor space than appears necessary should be allowed. Planning a laboratory with a bare minimum of floor space is a major mistake since future needs are usually unknown. Unforeseen personnel and equipment requirements will arise because new tests and procedures are constantly being developed. Therefore at first it is wise to use only part of the floor space and have additional space available for expansion. Compact laboratories reduce fatigue and increase production per technician. Additional floor space can be put into use as needed.

Management should make clear to all key personnel the cost involved in operating a laboratory. Many large, elaborate laboratories have been installed without other departments realizing the monthly cost which would be allocated to them for maintaining the laboratory. Discontent has resulted purely because anticipated costs were not understood.

Top laboratory personnel should be allowed time to visit manufacturing plants which supply bakery product ingredients. Visits to such plants permit the chemist to understand not only production problems but the routine testing done by the manufacturer. Such visits should materially reduce the necessary testing within the bakery laboratory.

SMALL LABORATORY LAY-OUTS

A 2 or 3 man laboratory requires economy of space and equipment, and attention to a convenient location. So many factors are involved in these three considerations that great care must be taken in planning so that all three are given full attention.

A small laboratory should allow approximately twice the space it will use initially. A long and narrow room will provide greater efficiency than a square room of equal floor space. Wall work-benches and center work benches are the work areas. The aisles between these should be wide enough for workers to pass each other but no wider. Figure 197 shows the right and wrong way to build the laboratory for the most efficient use of floor space.

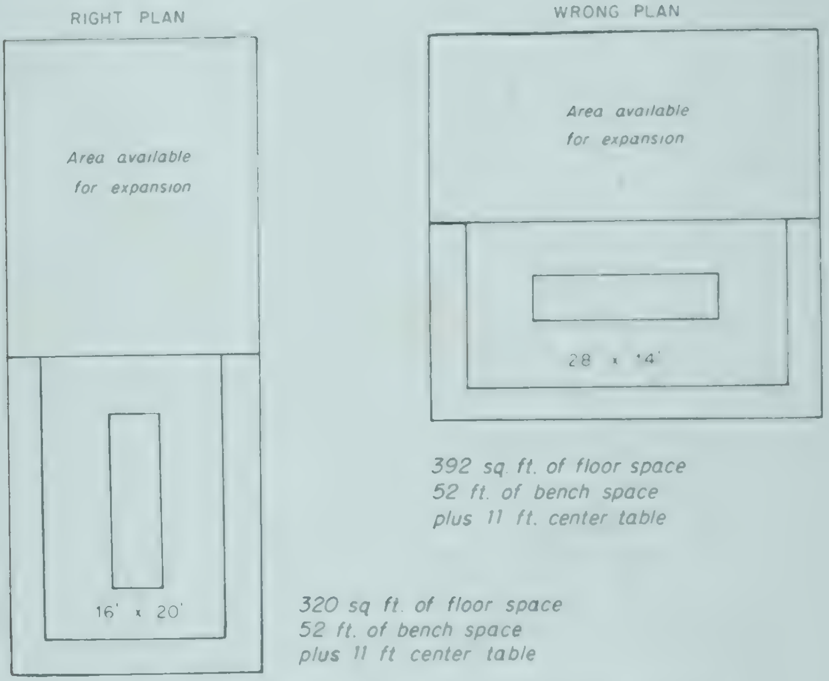

RIGHT PLAN
Area available for expansion
16' x 20'
320 sq ft. of floor space
52 ft. of bench space
plus 11 ft center table
WRONG PLAN
Area available for expansion
28 x 14'
392 sq. ft. of floor space
52 ft. of bench space
plus 11 ft. center table

Fig. 197. Examples of Laboratory Planning

Before any attempt to plan laboratory lay-out is undertaken, it is necessary to consider air conditioning, outside light, plumbing, gas and electricity. If the laboratory is to be located in the bakery, where should it be located to take advantage of all of these three factors? In some cases, it might be economical to move and rearrange heavy bakery equipment to make room for the laboratory in a particular area to take advantage of these factors. At times, it might be wise for the laboratory to use extra office air conditioning. At other times, the location of the laboratory might be determined by source of electricity or convenience of plumbing. Careful study of all factors in selecting laboratory location should prove valuable in years ahead.

Air conditioning a laboratory provides a problem. The cost of air conditioning a room housing protein apparatus, ash muffles, bake ovens, and moisture ovens is very high because the air conditioning unit must be large enough to overcome the heat put out by such equipment. Often it is good planning to have a separate room to house such equipment and to have no air conditioning in that room. However, efficiency of operation of laboratory personnel should not be reduced materially to save the cost of air conditioning equipment.

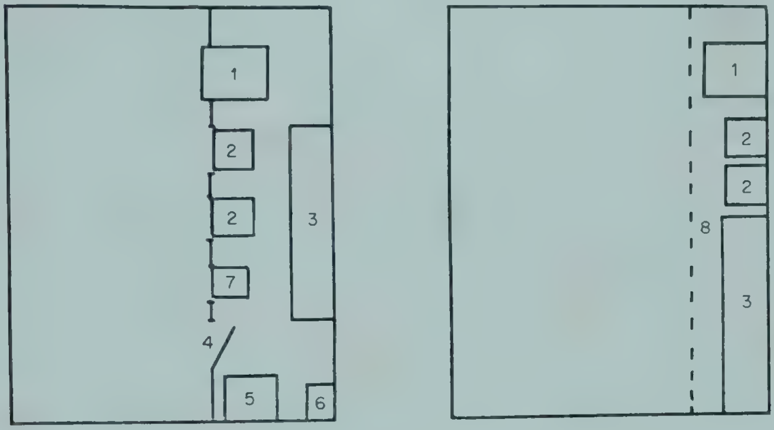


FIG. 198. METHODS OF SEPARATING HEAT GENERATING EQUIPMENT FROM AIR CONDITIONED LABORATORY

The plan on the left shows the heat generating equipment collected in a separate room while the plan on the right shows the equipment placed under a hood with an exhaust fan. Legend: (1) Bake oven; (2) Ash muffles; (3) Protein equipment; (4) Swinging door; (5) Sink; (6) Water still; (7) Moisture oven; and (8) Hooded area with exhaust fan to remove heat.

The cost of air conditioning is between 3 and 4 times greater when a unit is large enough to overcome the heat generated by laboratory equipment. Some laboratories have been designed with such equipment outside the general laboratory without creating serious inconvenience or time loss to personnel. Fig. 198 shows two types of lay-outs. The separate room is much more efficient as far as eliminating heat is concerned, but somewhat awkward for laboratory personnel since they must enter the hot room to make protein determinations. The protein titrations can be done in the air conditioned area. The hooded area as shown in this same Fig. 198 is in the general laboratory. This design would remove considerable heat but the air conditioning requirements would still be approximately twice that required for the separate room design.

The scope of testing and the number of samples to be tested should determine the size of the laboratory. Therefore, a two- or three-man laboratory should do only limited testing. Of first importance to any bakery laboratory is the laboratory bake shop. Minimum equipment for a yeast-leavened bakery laboratory consists of mixer, sponge cabinet, dough drawer, molder, proof cabinet, and bake oven. In addition, much small equipment such as scales, burettes, troughs, pans, compressometers, etc., would be needed.

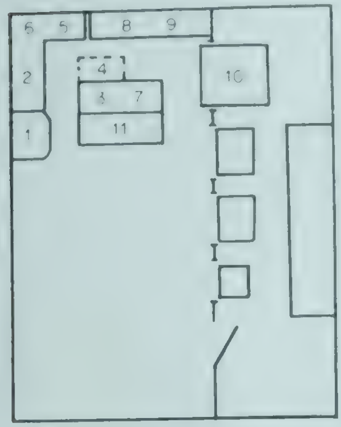


FIG. 199. LAYOUT FOR A ONE MAN LABORATORY BAKE SHOP

(1) Sink; (2) Sample table; (3) Flour scales; (4) Dough drawer; (5) Mixer; (6) Absorption burette; (7) Table molder; (8) Sponge cabinet; (9) Proof cabinet; (10) Bake oven; and (11) Bread cabinet and scoring table.

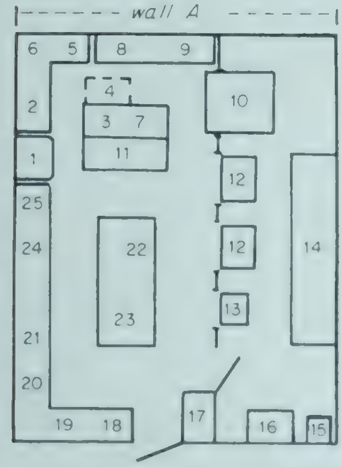


FIG. 200. LAYOUT FOR A TWO OR THREE MAN LABORATORY

(1) Sink; (2) Sample table; (3) Flour scales; (4) Dough drawer; (5) Mixer; (6) Dough burette; (7) Table molder; (8) Sponge cabinet; (9) Proof cabinet; (10) Bake oven; (11) Bread cabinet and scoring table; (12) Ash muffles; (13) Moisture oven; (14) Protein equipment; (15) Water still; (16) Sink; (17) Protein titration equipment; (18) Boiling water bath; (19) pH meter; (20) Microscope; (21) Incubator for bacteriological studies; (22) Farinograph and amylograph; (23) Analytical balance; (24) Fat extraction apparatus; and (25) Viscosimeter.

The baking equipment should be set up in proper sequence so the operator could move from flour to scales to mixer, to sponge cabinet, to mixer, to drawer, to molder, to proof cabinet, to oven, and to the scoring table. The baking laboratory should be in an area where no other analytical work is done. This would give the baker freedom to move quickly with no interference from fellow workers. Fig. 199 shows a sample lay-out for the bake shop for one-man test baking. A second mixer and a second oven need to be added if cake baking is to be done in the same laboratory.

The chemical laboratory would require more space because of the variety of equipment and procedures. A chemical laboratory would need a protein still and digester, ash muffle, moisture oven, fat extractor, pH meter, farinograph, amylograph, analytical balances, viscosimeter, autoclave, microscope, and water still. In addition to this large equipment, the laboratory would need a variety of glassware, crucibles, moisture dishes, etc.

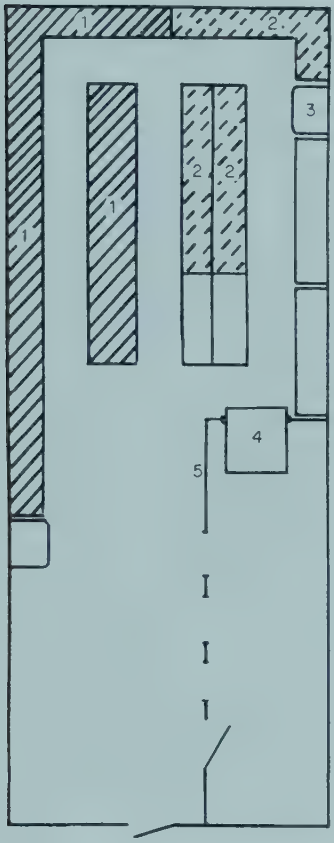


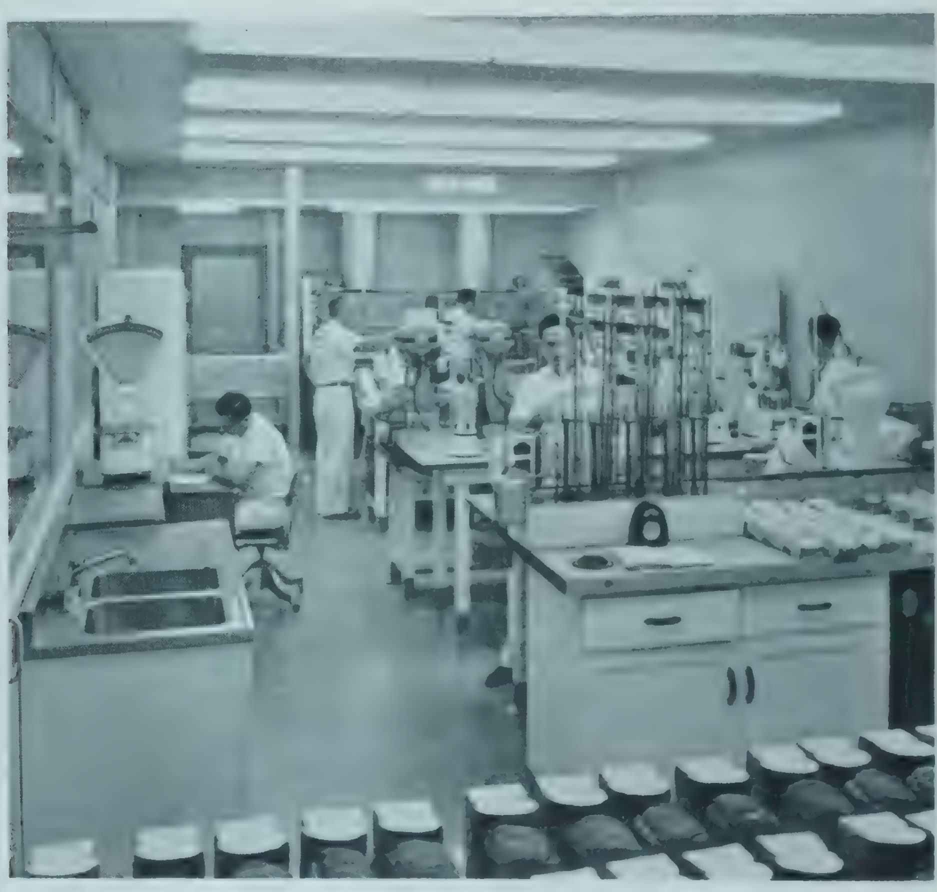
Fig. 201. Expansion of a Two or Three Man Laboratory to Make a Six Man Laboratory

Wall "A" in Figure 4 has been removed and the laboratory doubled in size. Legend: (1) Increased work area for general laboratory; (2) Increased work area for baking laboratory; (3) Sink installed in baking area; (4) Oven turned to face new baking area; and (5) Old oven opening sealed.

The chemical laboratory equipment should be added to the bake shop equipment as shown in Fig. 200. As the laboratory enlarges, *Wall A* could be moved because no permanent plumbing or wiring need be placed in this wall. The bake shop equipment would become a straight line operation suitable for two men. The bake oven is turned around to face the new baking area. The opening for the oven in the old laboratory is sealed and the new oven opening is placed in the new wall as it is constructed. Fig. 201 shows the increased laboratory with *Wall A* removed and the new walls constructed. Both the baking and chemical work areas have now been increased to allow for additional testing. The shaded area in Fig. 201 shows the space added to the test bakery and to the general laboratory.

LAY-OUT FOR A LARGE BAKERY LABORATORY

In laying out a large bakery laboratory, it is necessary to reconsider the scope of routine testing and to allow space for research. Requirements for power, gas, lighting, and air conditioning should be given the same consideration for a large laboratory as for a small one. Every test to be run in the large laboratory should be predetermined, and the number of tests per day should be given study. Of great importance in a large laboratory is making full use of all personnel every hour of the working day.



Courtesy of Rodney Milling Co.

FIG. 202. A LARGE LABORATORY BAKERY FOR YEAST LEAVENED PRODUCTS

As an example, let us assume that one man will be assigned to do certain special assays. The required number of these assays may only occupy four-fifths of his work week hours. This leaves one-fifth of his time available for help in other areas. Quite often, this time may be available only periodically. In this case it is important that his time be used in a work area close to his own laboratory. It is entirely possible that this man may be available one hour one day and as much as five hours another day. His supplemental work should be of a nature such as to permit him to work whenever he has free time. Sometimes rearrangement of procedures would permit a man to have a definite time every day for help in other departments.

In a large laboratory, work needs to be departmentalized, so laboratory lay-outs should also be departmentalized. The baking department must cover all types of anticipated baking and must be large enough to allow proper deploying of personnel so no interference or confusion will occur. If both chemically-leavened and yeast-leavened products are to be baked routinely, sufficient floor space should be allowed for concurrent baking. Fig. 202 shows a large yeast-leavened laboratory bake shop. It is obvious that even though the bake shop is large, there is no room for additional personnel to bake cakes concurrently. For this reason, ample space and equipment should be set up to allow for all baking anticipated.

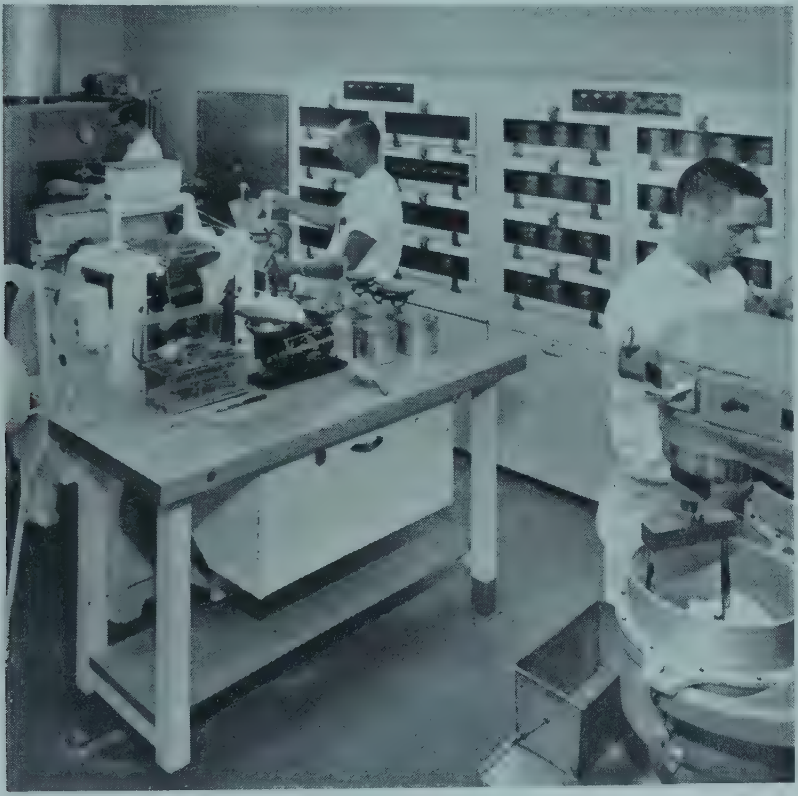


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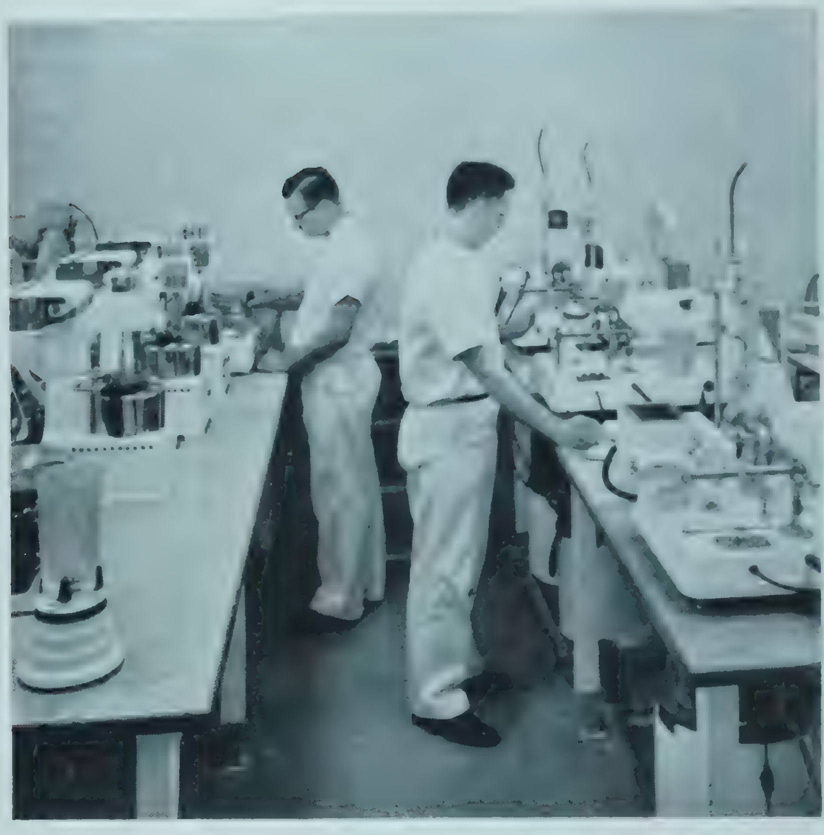
FIG. 203. A CLOSE-UP OF THE BAKING AREA

To show how personnel are placed to avoid interference between workers some close-up pictures of this same yeast-leavened laboratory



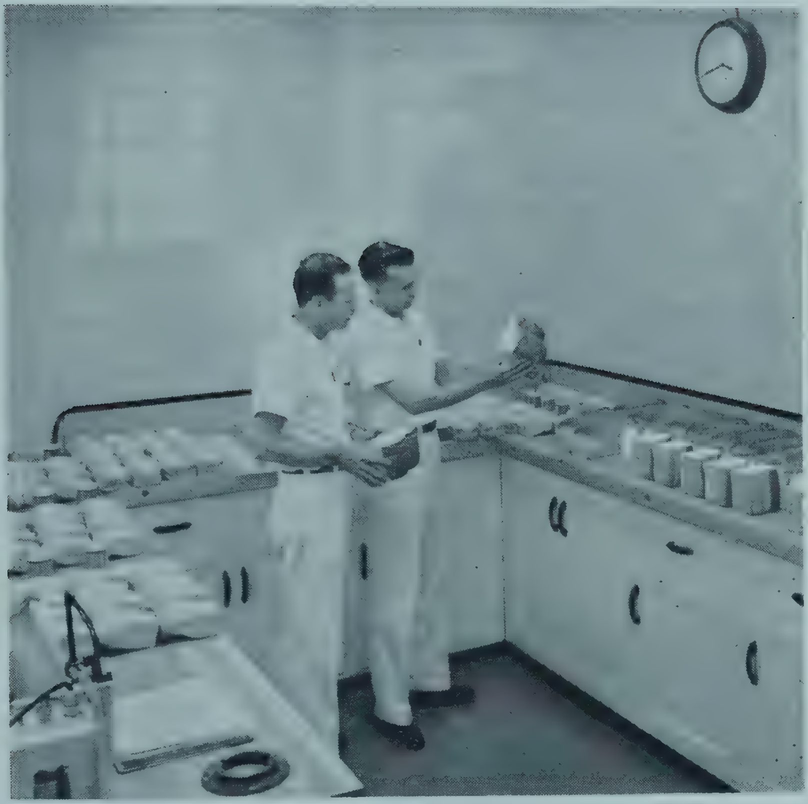
Courtesy of Rodney Milling Co.

FIG. 204. A CLOSE-UP OF THE FARINOGRAPH-AMYLOGRAPH AREA

bakery should prove helpful. Fig. 203 shows the baking area. It is compact, yet arranged so that the mixer, molder, and oven men do not interfere with one another. Fig. 204 shows the farinograph and amylograph work area in the baking laboratory. Men work here in an area that no other technician need enter. The same is true of the bread scoring area as shown in Fig. 205.

The protein, ash, malt, and moisture laboratory could be divided into two rooms joined by a swinging door. The balances, ash muffles, moisture ovens, and maltose equipment could be in one air conditioned room and the protein equipment in an adjoining room not air conditioned. Fig. 206 shows the balances and hooded ash muffle. The ash muffle hood closes completely by lifting the bottom sliding door. The small squirrel-cage type exhaust fan in the top of the hood draws in a small amount of air through the ceiling. This prevents heat from the muffles from radiating into the air conditioned room.

Adjacent to this balance room is the protein room which is not air conditioned. The same balances used for ash, malt, and moisture determinations can be used to weigh samples for protein determina-



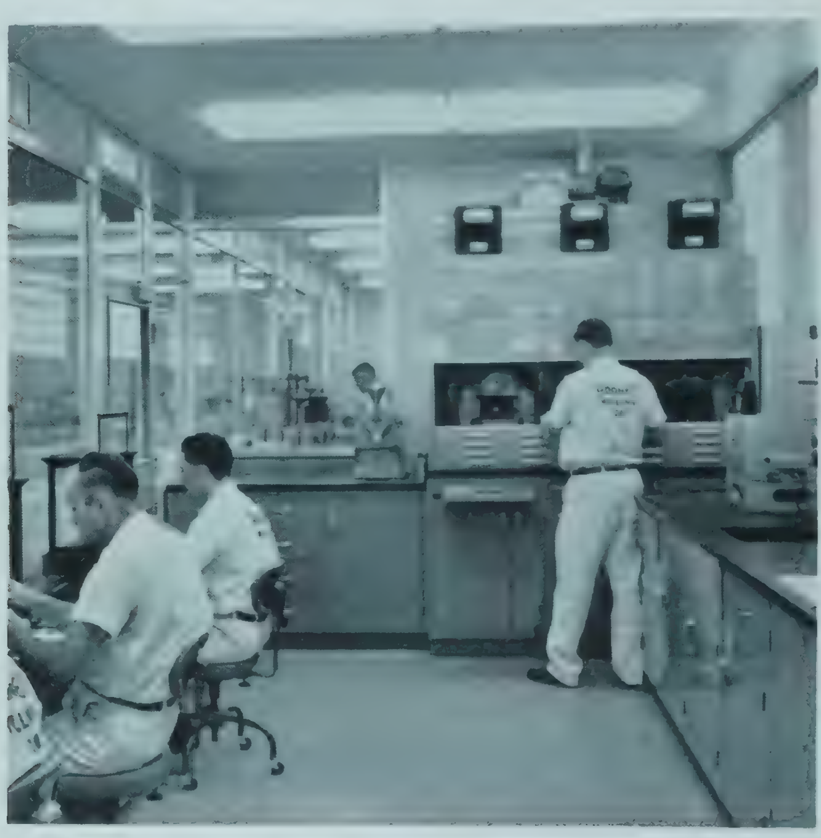
Courtesy of Rodney Milling Co.

Fig. 205. A Close-Up of the Bread Scoring Area

tions. After digestion and distillation, the distillate is returned to the air conditioned room for titration and calculation. Fig. 207 shows the protein equipment room. The louvered door at the far end of the protein room automatically opens to permit air to flow into the room as the ceiling exhaust fan removes the hot air. Since the balances are not in the room, high velocity air currents to remove heat create no problem and the technician has a comfortable working area.

The laboratory department allocated to sanitation analysis could be a small, compact room. A room twelve feet square is ample to run many such tests per day. This is a one-man laboratory so no space should be wasted. The bench along one wall should be desk height and the remaining bench area 36 inches high. The desk high area is for microscopic examinations and for writing up reports. The higher benches are for sample preparation, digestion, and separation. Work benches should be enclosed beneath the work surface for storage of both reagents and samples. This is true of all work benches except those that will be used while the technician is seated and leg room beneath the bench is required. Fig. 208 is a diagram of lay-out for the sanitation laboratory.

The nutrition laboratory can vary widely in size and design depending on the scope of its activities. If this department is to limit its activities to meeting label claims on enrichment, its size can be small. If assays for lysine, antibiotics, or B complex vitamins other than riboflavin, thiamin, and niacin are to be made, a much larger lay-out is necessary. Recent nutritional data indicate that bread is well suited to introduce micronutrients into the American diet. The contribution made by the baking industry to American health through the bread enrichment program is well recognized. It is reasonable to expect that other nutritional contributions will be made and the laboratory would do well to investigate procedures and a testing program for other nutritional supplements.

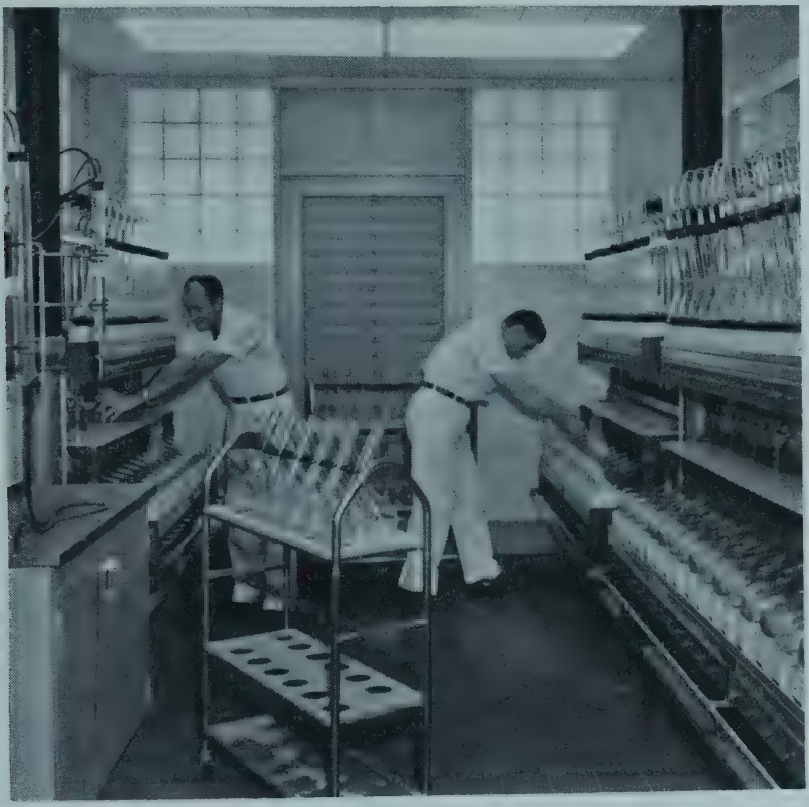


Courtesy of Rodney Milling Co.

FIG. 206. ASH, MOISTURE, AND BALANCE ROOM

A nutrition laboratory that will assay for riboflavin, thiamin, niacin, and iron should be a small, compact laboratory. Equipment necessary should include an analytical balance, a combination fluorophotometer and colorimeter, a centrifuge, a water bath, and a constant temperature cabinet. Small equipment such as a time clock, glassware, and proper shelves and racks would also be needed. In Fig. 209, a suitable lay-out for this laboratory is shown. One of the reagents used in niacin assay has a noxious odor so a small hooded area with an exhaust fan should be added to eliminate the fumes. This same hood could be used when boiling acid for the iron determination.

A laboratory for special studies of both finished products and products other than ingredients should be fairly large. In this laboratory, a large product scoring bench with a special daylight type of lighting fixtures would be required. Storage cabinets with temperature and humidity controls for the study of shelf-life, rate of rancidity, and related problems should be installed. In such a laboratory, moisture barrier wrapping material could be investigated. Off-odors due to paper, ink, or aromatic gases would require special study. Space should be allowed in this room for color comparisons, and equipment should be installed for the measurement of product volume and product weight. Shear test equipment, breaking pressure equipment, and a compressometer would be necessary in most bakery laboratories. A home freezer with a quick freeze compartment could be included if the bakery is producing frozen products of



Courtesy of Rodney Milling Co.

FIG. 207. THE PROTEIN EQUIPMENT ROOM

any kind. The lay-out of this special study and product testing laboratory could be as elaborate and all inclusive as the bakery can afford. However, a large room should be provided even if only partially used and equipped, since continually recurring problems may soon demand added space, equipment, and personnel. No lay-out is presented for this room because the size and equipment plan would depend on the knowledge and imagination of the laboratory director.

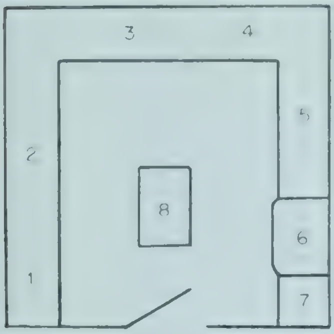


Fig. 208. A Sanitation Laboratory

(1) Report writing table (desk height); (2) Microscope area (desk height); (3) Sample preparation; (4) Hot plate; (5) Separatory funnels; (6) Sink; (7) Storage cabinet; and, (8) Rolling cart for samples.

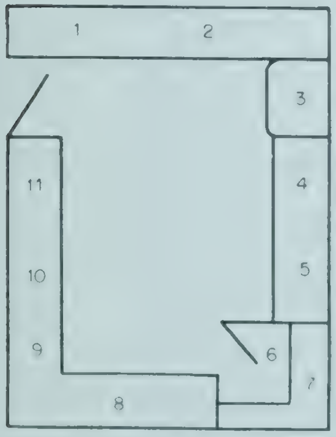


Fig. 209. A Nutritional Laboratory

Designed for thiamin, riboflavin, niacin, and iron analyses only. (1) Sample table; (2) Analytical balance; (3) Sink; (4) Hooded area and burners; (5) Constant temperature cabinet; (6) Dark room; (7) Fluorophotometer; (8) Sample preparation; (9) Centrifuge; (10) Boiling water bath; and (11) Ash muffle.

Another room of importance for the large departmentalized laboratory is the stock room or storage room. In addition to space for storing samples, glassware, and chemicals, the room should have space for equipment storage and a laboratory work bench with tools. Many chemists can be capable mechanics if they have the tools to work with and an area in which to work. Small but costly equipment repairs could be accomplished in this room, and so eliminate the cost of shipping equipment to the manufacturer as well as lost man hours while the equipment is out of the laboratory.

A practical research laboratory would depend on the area and type of research anticipated. If management desires practical research in the development of new products to be produced in the bakery, the research laboratory should be basically a baking laboratory. If research is wanted in the nutritional field, a research laboratory could be included in an expanded nutritional laboratory with sufficient space and equipment to do both routine work and research. For this reason the research laboratory lay-out depends on the area of investigation. Ample space for future expansion in the research laboratory is vital because one research project leads to another, *ad infinitum.*

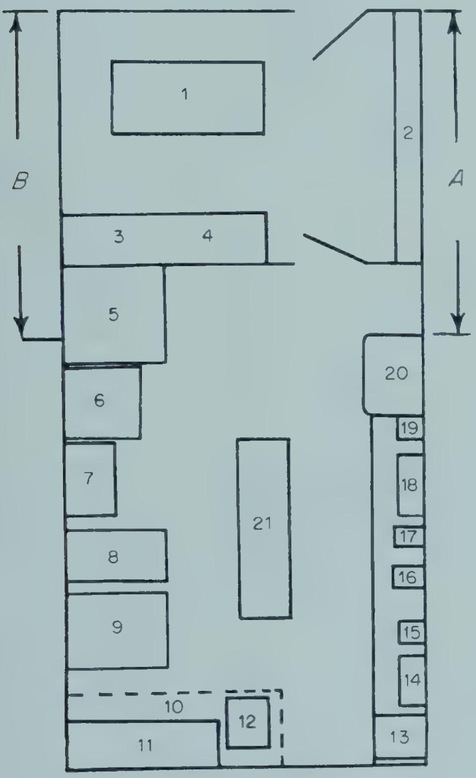


Fig. 210. Small Laboratory for Cake, Cookie, or Cracker Bakery

(1) Report-writing desk; (2) Library; (3) Microscope; (4) Analytical balance; (5) Finished product cabinet; (6) Constant temperature and humidity cabinet; (7) Refrigerator; (8) Bake oven; (9) Large incubator cabinet; (10) Hooded area; (11) Protein equipment; (12) Ash muffle; (13) Moisture oven; (14) Small incubator cabinet; (15) Centrifuge; (16) pH meter; (17) Viscosimeter; (18) Fat extractor; (19) Water still; (20) Sink; and (21) Dough work bench and mixer.

A small room for writing up reports and calculating results could be provided adjacent to the office of the laboratory director. This room should contain a typewriter, and adding and or calculating machine, report files, and several desk height work benches. This room would be used by all personnel in the final preparation of reports, and for general meetings of personnel with the laboratory director. The research library could either be in this room or in the office of the director.

COOKIE, CRACKER, AND CAKE BAKERY LABORATORY

The space and equipment required for this type laboratory would be different in some respects and similar in others. The floor space required for a small 2 or 3 man laboratory would be greater because of added specialized testing and larger equipment. The basic consideration as to

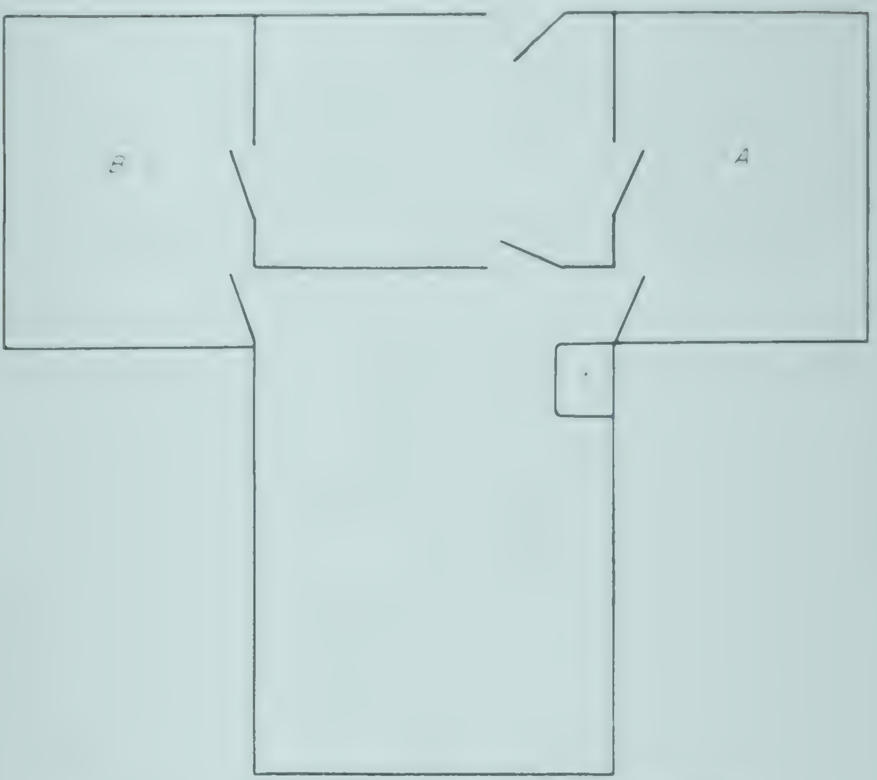


Fig. 211. Expansion of a Small Laboratory

The sink in the old laboratory is now at (1). Expansion can go in direction of either "A" or "B." "A" has some plumbing advantage.

location of laboratory, additional available space, and air conditioning would be the same for this type of laboratory as for the yeast leavened bakery laboratory.

The equipment essential for such a laboratory should include protein equipment, ash muffle, moisture oven, viscosimeter, fat extractor, centrifuge, microscope, analytical balance, bake oven, mixer, molder, refrigerator, several humidity and temperature-controlled cabinets, incubation cabinet, and pH meter. In addition, the necessary glassware, cookie sheets, cake pans, moisture dishes, ash crucibles, etc., would be required.

The laboratory lay-out could be as shown in Fig. 210, or the analytical balances could be brought out into the general laboratory leaving microscopic and sanitation work in the laboratory office area.

As the laboratory grows, *Wall* A could be removed, and expansion could be in that direction. A door could be put in *Wall* A between the sink and the office door if this would provide a better work area in the enlarged laboratory. Many arrangements can be considered in the expansion of this lay-out. Fig. 211 shows two diagrams of expansion lay-out possibilities. Expansion could go in either direction; however, an added room should have office access.

As this type of laboratory expands, it would be necessary to departmentalize somewhat. The first step would be to have a separate baking laboratory. Included in the first expansion would be a product study laboratory including a constant temperature humidity cabinet, storage space for baked products, space for baked goods scoring and for special problems. When this equipment is moved from the original laboratory, considerable added work area would become available for the general chemical laboratory. This added space, with some rearrangement of equipment, would permit several technicians to work where only two could work before.

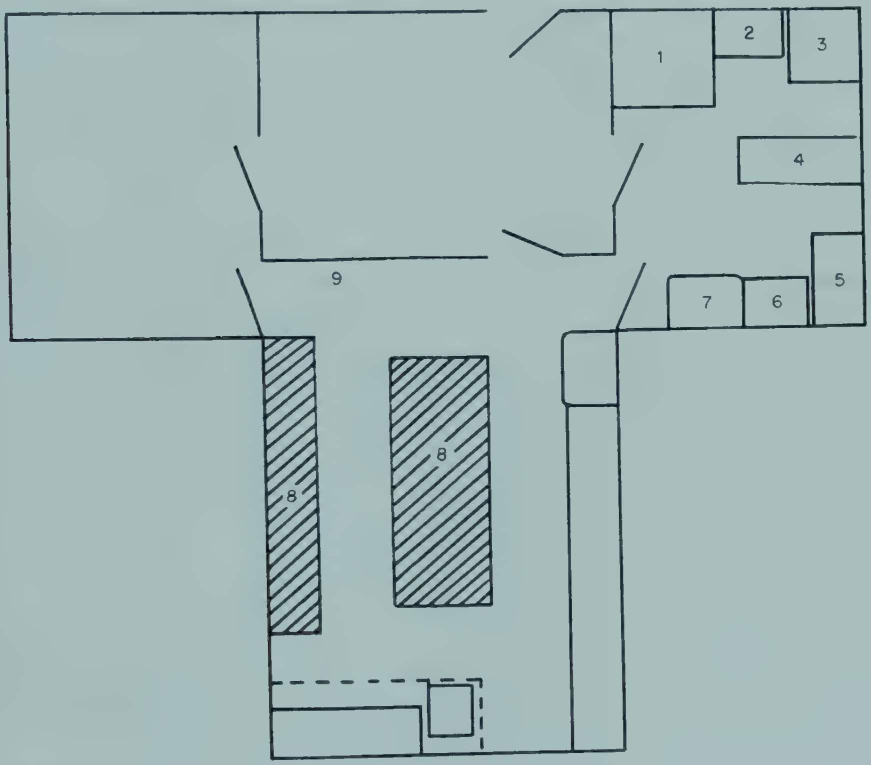


Fig. 212. Expanded Small Soft Wheat Flour Laboratory for Six Men

(1) Finished product cabinet; (2) Refrigerator; (3) Constant temperature and humidity cabinet; (4) Dough work bench; (5) Bake oven; (6) Mixer bench; (7) Sink; (8) Added work area for general laboratory; and (9) Additional work area available if the laboratory on the left is not added.

A baking laboratory, including product cabinets and refrigerator, could be set up for two-man operation in the new area. The bake oven would need to be moved into the new area, which might require removing some of *Wall A*. The new area could be arranged as shown in Fig. 212. The baking area would have enough room for a two-man operation with its own door to the office for report writing.

The chemical laboratory would be increased in area so that sanitation work could be moved in from the office and new equipment could be added. This enlarged chemical laboratory could accommodate as many as four men.

There are many ways of enlarging a laboratory if the space is available. This is the reason it is so important to build the first small laboratory in a manner that will permit expansion with the minimum of cost. Plumbing and wiring should be avoided in a wall that may be removed. Extra power and plumbing should be included in the original plans so when it becomes necessary to expand, the extra sources can be tapped.

REPORT FORMS AND INTERPRETATION OF LABORATORY RESULTS

Perhaps the laboratory report forms and the interpretation of these forms is one of the most controversial matters in the baking industry. Importance is often attached to differences in results that are within the experimental error of the laboratory. A baking report can give production figures which can in most cases be applied by production; however, this is not always possible. For example, the laboratory baker can determine the absorption of a flour down to a fraction of one per cent, yet the production department cannot always take this figure and apply it to the large dough mass used in the bakery. This could be because the mixing action of the bakery mixer is different from the mixing action of the laboratory mixer, or for any one of several other reasons. Many examples of poor correlation between laboratory results and production results could be cited.

Laboratory results should be taken as indexes that point to some basic difference, but the laboratory can seldom give positive figures that can be taken as a whole and applied in production. If the laboratory says a flour has a two per cent higher absorption, and production finds it only has one per cent higher absorption, both the laboratory and production should accept this fact. Soon production will find that by the application of a factor to laboratory absorptions, the figures become applicable in production. This principle applies to many laboratory tests. Even the protein determination must be considered in the light of the findings of many laboratories collaborating on the same sample. The fact that a laboratory is always one-half per cent high on collaborative protein tests does not necessarily prove that the laboratory is wrong. It merely proves that laboratory is high compared with results of several other laboratories.

The laboratory must point out to production differences between shipments of ingredients that are significant to production. If the ash of a flour goes up from .420 per cent to .440 per cent, and yet the baking properties are unchanged and the flour color is unchanged, the difference in ash is of little importance to production. However, this same difference in ash may be very important to the purchasing department if flour is purchased on an ash specification. Therefore, it is important for the laboratory to bring to the attention of the proper person variations in ingredient analyses. Often a department head will use variations that have no bearing on his own job as an excuse for his own failures. For this reason, the laboratory should be sure that all significant variations are brought to the attention of the proper department heads.

There are many types of laboratory report forms in use. Almost all laboratories evolve a report form pattern which fits the needs of all departments of the bakery. A few laboratories have one form for the production department, another for the sanitation department, another for the purchasing department, etc. In the latter case, management receives copies of all reports for all departments.

It is almost impossible to design a report form that is all inclusive; for this reason many laboratory directors make up report forms for each department. Variations found in ingredients are of interest both to production and purchasing departments. Variations in finished products are of interest to both sales and production departments. Sanitation analyses of ingredients and sanitation analyses of finished products are also of interest to different departments. All laboratory results should be of interest to management.

After discussing report forms with all department heads, it is necessary to design forms that are satisfactory to all concerned. Production will want a copy of all ingredient and finished product analyses except possibly sanitation. In cases where whole insects, larva, or rodent excreta pellets are involved, the problem is usually in the plant and is important to both production and sanitation. In such cases, production will want and should have sanitation analysis results. Sales will want complete laboratory results on finished products except possibly routine vitamin and sanitation analysis. If there is a man in the organization specializing on labels and Food and Drug requirements, he will want laboratory reports on product weights, vitamin assays, and sanitation of finished products. The purchasing department will want results from the laboratory on everything purchased including ingredients, wrappers, cartons, equipment, oils, greases, etc. The maintenance department needs to know if equipment fragments or grease show up in products and also if there is any damage to products due to faulty operation of equipment. The number of copies of laboratory reports will vary depending on the number of departments affected by results.

A report form designed for the production department should include the analyses of ingredients and finished products. Such a form can be designed in many different ways depending on the demands of the production department and the number of analyses carried out in the laboratory. Many laboratories will have one report form for flour, another for milk, and still a third form for other ingredients. In designing a report for the production department, it is necessary, of course, to include baking results. Therefore, the production report form for flour must include protein, ash, moisture, color, farinograph, amylograph, and baking results. The production department's report on milk should include, in addition to the chemical analyses, a report on its performance in test baking. Separate report forms for lesser ingredients need not be made up in a standard form, since the laboratory will test routinely other ingredients used both chemically and in laboratory baking tests. Therefore a regular baking report form will give the production department the necessary information needed when two different types of yeast food, sugar materials, or diastatic malts are compared. In addition to report forms for ingredients, it will be necessary to have standardized forms for reporting the quality of finished products. This will include various systems of scoring products, scale weight, performance of slicer and wrapper, and any other information which the laboratory and production departments agree are important to measure the quality and uniformity of products produced.

The report form for the sales department should be limited to finished product scoring, weighing, compressibility, shelf life, slicing and wrapping. It is a simple matter to design the production department's product scoring form so that a copy can be submitted to the sales department.

Report forms for the sanitation engineer should include laboratory sanitation analysis only. Whenever whole insects, whole larvae, or whole rodent excreta pellets are found, the report should go to the production department also, since it indicates an "in the plant" problem. Such a problem needs the combined efforts of the sanitation engineer and the production superintendent. Sanitation reports showing insect fragments, rodent excreta pellet fragments, or rodent hair in the finished product would indicate that the problem is probably in one of the ingredients used in production. After the contaminated ingredient is located by analysis, the contaminated ingredient must be reported to the purchasing department so that the department can set up stricter specifications.

Occasionally the maintenance department will need a copy of either bread score or sanitation reports when certain conditions affecting the finished product can be traced to that department. Machine grease or metal equipment fragments found in finished products, as mentioned before, should be reported to the maintenance department.

The report forms for the purchasing department should be designed specifically for them to cover not only ingredient analysis but periodic tests of wrapping materials, cartons, oils, greases, and other products purchased which require a laboratory check for uniformity and quality. On the special report form for this department, room should be left for the chemist to write in any specific observations production-wise of importance to the purchasing department.

It is impossible to have a standardized report form suitable for new product development reports. Such reports will have to be written in detail and submitted to management and sales departments along with samples of the products involved. It is important to remember that new product development is a two-way program. The sales and management departments should submit in written form any ideas they have regarding new products for the laboratory to investigate, and the laboratory should in turn report back its progress in new product development.

Many special studies involving shelf-life of products produced in the bakery will require written reports. Such reports need to be detailed and specific in some cases and generalized in others. Therefore any sort of standardized report form is impossible for this use. The technique and the study of ingredients used when considering shelf life of a product will vary with each product studied.

All product testing in the laboratory should be designed to bring out the maximum effect of operating, ingredient, and formula variations. Unless significant differences are reported, the reports become ineffective. Showing slight variations which cannot be found in actual commercial production will mean nothing to the sales department, production department, or management, and therefore should be avoided even though they are reproducible under laboratory conditions. On the other hand, when truly significant variations are observed in the laboratory, these should be brought to the attention of all departments concerned, with sufficient emphasis so the results will be observed. For this reason, all report forms should be designed with the thought in mind that small variations are insignificant, whereas large variations demand attention and action.

RELATIONSHIP OF THE LABORATORY TO MANAGEMENT

The laboratory must be directly under management and completely divorced from all other departments. If a laboratory is placed under the control of the production department, the laboratory loses its independent approach to production problems. The same situation would exist if the laboratory is put under the sales department, the purchasing department, or any other department. If it is under the production department, there may possibly be a conflict of goals which will prevent the laboratory from reporting all findings in an unbiased fashion. The production department will want high scores on all finished products. When production problems arise, pressure will be put on the laboratory to find fault with equipment or ingredients; therefore, pressure which might effect its findings can be avoided only if the laboratory is responsible directly to management.

Friction can also be caused by the difference in evaluation of products by the production and sales departments. The sales department may claim that the products are not up to standard quality-wise, or are staling too fast, or are off-color. Production, on the other hand, may claim that the products are as they have always been and so disagree with the sales department. The laboratory can step into this breach only if it is completely independent of both departments. Then laboratory studies of sales complaints can be unbiased, and both the production and sales departments can depend on laboratory findings.

Management should find out what each department requires from the laboratory and should convey these requirements to the laboratory director. When additional testing is required in the laboratory, this information too must come directly from management. All activities of the laboratory, therefore, are directed by management, even though management may have nothing to do with determining what specific tests are required.

The laboratory director should be invited to sit in on weekly conferences between management and department heads. At times it may be appropriate for a laboratory man to sit in at sales and promotion meetings so that he fully understands the problems and methods of those departments. Certainly the director of the laboratory can be of great help to the production superintendent in periodic meetings with personnel. By complete cooperation with all departments, the laboratory will be of greatest service to the baking company.

USING THE SERVICES OF CONSULTING LABORATORIES

There will be many times and occasions when management can make use of consulting laboratories. Laboratories which specialize in certain fields can be of great help in supplementing work done in the bakery laboratory. Laboratories specializing in almost any field can be found to handle special problems economically and quickly. Bacteriological laboratories can be of genuine service when problems of this type arise. Being specialists in bacteriological work they can often spot trouble and suggest a remedy quickly. When the problem involved is of a specialized nature, full consideration should be given to outside laboratory help before having work undertaken in the bakery laboratory.

Probably more bakery laboratories have their vitamin assay work done by outside laboratories than do the work themselves. The vitamin assay work is not a routine test that needs to be done daily, and therefore cannot be set up on a regular schedule like other laboratory testing. Assuming that this needs to be done once monthly on a variety of products, it will throw a tremendous load on the vitamin laboratory at one time. As soon as the work is completed, the vitamin laboratory will not be busy until the next group of samples is received. Staggering sample arrival will not always accomplish the desired result in maintaining uniformity of laboratory load. The cost of outside laboratory vitamin analysis is also a factor in deciding whether or not this testing should be done by an outside commercial laboratory. If it can be done in the bakery laboratory for less than one-half the cost of having it done in a commercial laboratory, the inclusion of a vitamin laboratory is justified (the cost mentioned refers to personnel man hours only).

In many cases, it may be advisable to have all sanitation analysis done by a commercial laboratory specializing in this field. In other cases, bakeries have a sanitation service which includes fumigation, inspection, and sanitation analysis. Costs for both types of laboratory service should be evaluated against costs of having the same work done in the bakery laboratory. A decision can be made on the basis of cost, keeping in mind the convenience of in-the-plant testing.

The economics of using outside laboratories to supplement work done in the bakery laboratory are often worth-while. Whenever a large number of tests are required for a short period of time, it is wise to investigate the possibility of using the services of a commercial laboratory capable of making large numbers of such tests quickly and routinely. For example, if a bakery decides it would like to have the total sugar analysis run on all products produced, the sugar determinations would be very time consuming and expensive in the bakery laboratory and might be more economically done by a commercial laboratory.

It is wise to keep in mind at all times the possible use of commercial and consulting laboratories. The time required for the analysis and the man hours lost are the principal considerations in deciding when to use outside help. Specialized laboratories should be considered whenever specialized problems arise.

LABORATORY PERSONNEL

Sources of laboratory personnel fall into the categories of university trained scientists, and trade school or experience trained technicians. University trained men need not be trained specifically for the cereal industry but may be trained as general chemists, organic chemists, or chemical engineers. Any good university graduate with a major in chemistry should develop into a capable technologist for the bakery laboratory. The degree of training of laboratory technicians should determine their potential in routine as well as creative work.

There are many good schools for training bakery personnel but relatively few specializing in the field of cereal chemistry. The University of Minnesota, the University of Nebraska, Kansas State University, Oklahoma State University, and Florida State University have departments where it is possible to major in cereal chemistry or in a closely allied field. Such graduates would have an advantage over graduates from schools not specializing in these subjects. Florida State University and Oklahoma State University have special baking school departments which provide excellent training for potential bakery laboratory personnel. Kansas State University has the added advantage of a flour milling and feed milling school on the campus which provides its students with an insight into the background of baking chemistry.

Such schools as the American Institute of Baking, the Siebel Institute, the Dunwoody Institute, and many others provide excellent training for non-university graduates who would like to become laboratory technicians. The old adage that there is no training like experience is also true for laboratory personnel. People who have had years of experience in a cereal laboratory where baking is done routinely can prove very valuable in a bakery laboratory.

In selecting laboratory personnel, many factors must be considered. The director of the laboratory must get along well with other people. After this consideration, his academic background and experience should determine his suitability.

Selecting other personnel should primarily be on the basis of laboratory experience. Laboratory technicians familiar with one type of analytical work can quickly adjust to another type of work. Of more importance is the consideration of an applicant's ability to do routine analytical procedures quickly and accurately.

It would be up to the laboratory director to train each member of his staff to do the work as he wants it done, using the procedures and techniques that he prescribes. He should train his personnel to turn out volume results according to his direction and with accuracy within the limits of the test.

Every member of his staff must be directly responsible to the laboratory director and to him alone. Before final reports are made up, the director of the laboratory should look over all results and make sure they are correct. Whenever a result appears to be out of line he should ask the chemist involved to recheck his work. Accuracy in the laboratory is the keystone that holds the laboratory closely to all other departments in the bakery because accuracy builds confidence.

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